CHAPTER 1

INTRODUCTION

1.1 Background

Long time ago when humans have inhibited this planet, they have sought to protect themselves from exposure to harsh weather conditions. Nowadays many people spend most of their time indoor where the climate is controlled artificially to achieve required thermal comfort and occupant's satisfaction. In order to enhance comfort and well being of the occupants of any building, thermal requirements are controlled with extensive and often complicated HVAC control systems.

Buildings are designed and erected for people to serve as shelter and to provide them with comfortable environment. As a result of growing types of industries and technologies large industrial and office buildings have been constructed in large scales. Therefore excessive amounts of energy are consumed daily. This would ultimately mean that large sums of money will be spent in providing buildings with their energy demands.

More specifically, office buildings need HVAC systems in hot and humid climates such as those of Saudi Arabia. These buildings can also use energy efficiency measures and renewable energy technology to minimize burden on the environment. We might ask: what are the energy conservation measures? There is a wide range of measures in all categories. To reduce the buildings heating and cooling expenditures, there are two broad courses of action that may be taken. First, begin with passive measures to assure that a building and its existing components function as efficiently as possible without the necessity of making alterations or adding new material. The second course of action is preservation retrofitting, which defines altering the building by making appropriate weatherization measures to improve thermal performance.

Undertaking the passive measures and the preservation retrofitting recommended could result in a 50% decrease in energy expenditures in office buildings [1]. So different energy conservation measures can be determined, which do help achieving energy efficiency and thermal comfort. Energy conservation is a key issue in most office buildings. In any office building, office employers use different equipments for their works like photocopying machines, printers, computers and of course lighting. It is essential that after the completion of that study, energy efficient measurements should be provided so that their electric bills and other energy consumption equipments which consume lot of energy should be reduced.

Previous research studies have indicated that buildings consume about 40% of the annual energy in the United States [2]. In addition, huge amounts of that energy can be conserved and saved through proper design strategies. For instant, the Gulf Cooperation Council (GCC) countries along with Saudi Arabia which is member of this council can save up to 33% of the annual energy consumed in buildings through using appropriate thermal insulation [2].

Consequently, the need to conserve energy in buildings has reintroduced the fact of the importance of providing thermal comfort without the wastage of energy. It has been well-known that among the major contributors to energy consumption in buildings are air-conditioning systems. One important aspect of air-conditioning systems is the heating and cooling loads. It appears that some fundamental re-considerations are essential in space heating and cooling so as to reduce energy consumption. Indoor comfort is now being thought of as the second primer cause for designing the building after satisfying human sheltering need. Thermal comfort is simply defined as "the state of mind which expresses satisfaction with thermal environment" [2]. A human being is said to be thermally comfortable when he can not decide whether he would prefer cooler or warmer surroundings [3].

1.2 Statement of the problem

Office buildings constitute the heart of any business category so its design, construction and operation of its various systems particularly HVAC systems and their impact on energy consumption must be thoroughly considered. Knowledge about the actual thermal characteristics and operation of energy systems of office building in the environmental context of Saudi Arabia is lacking.

1.3 Objectives of the study

The primary objective of the proposed research project is to study the impact of HVAC systems design and operation on energy requirements for an office building in hot and humid climates in Saudi Arabia.

The specific objectives are:

1. To determine the efficient type of HVAC systems for achieving required thermal comfort in the proposed office building at minimum energy use.
2. To determine the operational measures that can conserve energy and the impact of these measures on HVAC systems energy requirements.
3. To prioritize the feasible, practical and operational measures that can produce significant savings on energy cost.
4. To develop guidelines for HVAC systems operation that can provide greater occupants comfort with potentially reducing energy consumption in similar office buildings in hot and humid climates of Saudi Arabia.

1.4 Scope and limitations

The aim of this research is to minimize the electric energy consumption and demand required to achieve thermal comfort in office building through various operational and design related measures and with the use of different air conditioning systems. Conserving energy in office buildings is a concept which is growing very rapidly in Saudi Arabia. There are many ways by which considerable energy in the form of electricity can be saved by using appropriate techniques and we call them as conservation measures. There is great deal of demand in conserving energy in buildings especially office buildings. This study is limited to studying an office building in the hot and humid climates represented by the eastern province of Saudi Arabia.

1.5 Significance of the study

This study is significant for the owners and users of office buildings for finding suitable operational and design related measures. Office buildings need HVAC systems for occupants comfort and smooth flow of work. HVAC systems play a key role in energy consumption of office buildings. This study will show the current energy consumption in office building and the energy cost related to that. It will also show the changes in energy and cost if different types of A/C systems are changed. In this study, different HVAC systems will be taken into consideration for study and will get the impact of each system on energy conservation. Different operational and design measures of HVAC systems will be studied and then using DOE software appropriate design and operational measures will be provided for reducing energy consumption in similar office buildings.

1.6 RESEARCH METHDOLOGY

The research methodology has been divided into three phases as followsand summarized in Figure 1.1.

PHASE I:

Literature Review

In this phase, a study has been conducted and probed about previous research work by consulting different research papers and conference proceedings, published in the journals of international repute. This phase provides the guidelines and technique to achieve the objectives of this study. Different HVAC systems have been studies for the selection of appropriate system that can provide less energy consumption with greater occupant's comfort. Moreover, different designs and operational measures have been studied for the purpose of conserving energy.

PHASE II:

Data Collection

In this phase, evaluation of the office building was conducted and frequent visits of the office building were arranged for data collection.

Figure 1.1: Research methodology chart

Data was collected in various forms as mentioned below:

- Building audit
- Questionnaire survey
- Field measurements and environmental parameters those are indicative of thermal comfort conditions in spaces

PHASE III:

Data Analysis:

In this phase, all collected information and data which was gathered in previous phase were analyzed .The following steps were adopted in analyzing the data:

- Analysis of preliminary data and field measurements to set the analysis approach and considerations
- Energy simulation using VISUAL DOE software and thermal performance evaluation of office building based on collected data
- Alternative systems operation as well as alternative design parameters was evaluated for this selected office building.

PHASE IV:

Thermal Design Guidelines

Based on the results and energy simulation evaluation, guidelines related to selection of appropriate HVAC systems, the list of various operational measures which were used according to priority was provided for improving thermal performance with minimum energy consumption in similar office buildings.

Building Description

A multi-storey news paper office building is selected for this research case study. This is six storey office building located in Dammam at 26^{o} towards North and 50^{o} towards east. A total floor area of the building is $12500m^{2}$ and floor to floor height at each level is 5.25 m. The walls of the building consist of 200mm concrete block and 50mm polyutherine. The roof consists of 200mm concrete block, 50mm polyutherine and inside layer. The type of windows is double glazed with 12mm air space in between. The window has shading coefficient of 30% and has transmittance of 70%. The HVAC systems used in the building is Constant air volume (CAV) system. There are twenty four Air Handling Units serving the different zones of the building. There are four reciprocating chillers with carrier compressors, condenser fan motor and chiller pump motor. The cooling of the building is provided by chilled water from the plant. All the chillers are controlled by the cooling demand of the AHUs. Each chiller has six compressors, ten fan motors and six chiller pump motors. Total capacity of one chiller is 739 KW.

Each floor has separate thermostat control. All the conditioned zones in the building have set points between 23^{o}C to 25^{o}C for summer and 21^{o}C to 22^{o}C for winter. All air handling units are controlled by timer and after 4pm it is set closed for some floors which usually become unoccupied after that time.

There are total six elevators in this office building. The facades located front of the building are having while color and other facades are having light blue color. Fluorescent lights are used in whole building. It has number of different equipments like personal computers, printers, scanners, and other electric equipments. Each floor contains two conference rooms. There is one mosque on first floor and one cafeteria on ground floor. Floor plans are attached in Appendix B.

Reasons for the Selection of ALYAUM Office Building

- ✓ Each floor has separate thermostat control
- ✓ This building has facades on all sides except on back wall of ground floor
- ✓ Concerned people will provide monthly utility bills and other essential information

- ✓ Building is located in hot and humid climatic conditions where huge amount of electric energy is consumed during summer months
- ✓ From all these factors taking into consideration, it can be said that it is a typical office building for assessing the impact of HVAC systems on energy conservation.

CHAPTER 2
LITERATURE REVIEW

2.1 HVAC systems

HVAC systems are an essential component of modern life, and when properly designed, installed, operated and maintained, provide healthy, comfortable and productive indoor environment. HVAC issues related to energy conservation are vital for the design of new buildings as well as for renovation of existing ones.

The energy use due to HVAC systems can represents 40% of the total energy consumed by typical office buildings [4]. The energy auditor should obtain the characteristics of major HVAC equipment to determine the condition of the equipment, their operating schedule, their quality of maintenance, and their control procedures. A large number of measures can be considered to improve the energy performance of both primary and secondary HVAC systems.

HVAC systems consist of any number of fans pumps, compressors, heat exchangers, cooling towers valves and dampers sizes as well as a pipe and air duct assemblies of different sizing and with different operating characteristics.

2.1.1 HVAC Systems Design

Heating, ventilating and air-conditioning (HVAC) systems are designed to provide control of space temperature, humidity, air contaminants, differential pressurization, and air motion. Most of the heating ventilating and air-conditioning systems are designed for human comfort; many industrial applications have objectives other than human comfort [1]. If human comfort can be achieved while the demands of industry are satisfied, the design of HVAC system will be much better and more economical.

Equipment Selection

From the calculations and the method of control, the capacity and operating conditions may be determined for each component of the system. Manufacturer's catalogs give extensive tables and sometimes performance curves for their equipment [1]. All equipment that moves or is moved vibrates and generates noise. In most HVAC systems, noise is of utmost importance. Many equipment test codes have been written by ASHRAE, American Refrigerator Institute (ARI), Air Moving and Conditioning Association (AMCA), and other societies and manufacturer groups. A comprehensive list of these codes is contained in ASHRAE handbooks.

Equipment Location

Mechanical and electrical equipment must be serviced periodically and eventually replaced when its useful life has expired. To achieve this end, every piece of equipment must be assessable and have a planned means of replacement [1]. Ceiling spaces should not be used for locating equipment. Servicing equipment in the ceiling entails erecting a ladder at the proper point and removing a ceiling tile or opening an access door, to gain access to the equipment.

Equipment should be located in spaces specifically designed to house them. Sufficient space should be provided so that workers can walk around pieces of equipment swing a wrench, rig a hoist or replace an electric motor, fan shaft, or fan belts. Do not forget to provide space for the necessary electrical conduits, piping and air ducts associated with this equipment.

Distribution Systems

HVAC distribution systems are of two kinds: Air ducts and piping. Air ducts are used to convey air to and from desired locations. Air ducts include supply air, return-relief air, exhaust air, and air-conveying systems. Piping is used to convey steam and condensate, heating hot water and other heat transfer fluids.

Energy is required to force the fluids through these systems. This energy should be considered when systems are evaluated or compared.

Thermal Zoning

For greater design flexibility and energy economics, an approach known as thermal zoning is commonly used in HVAC systems. . By subdividing a building into a series of zones, the set conditions can be maintained properly for a specific space and the equipment need service only the areas that require heating and cooling [5]. Combining zoning with night temperature set-back controls and a time clock is an effective means of achieving occupied and unoccupied building controls.

Although it is common to have many zones within one building, the number of occupied and unoccupied modes allowable in one day is normally limited to two each in any one zone, in other words the system can switch from occupied to unoccupied mode and back to occupied twice daily

2.1.2 HVAC system Operation and Maintenance

Correct HVAC system maintenance and proper operation characteristics can reduce overall equipment costs and improve energy efficiency. Care is taken in designing buildings and their systems and in selecting and sizing environmental conditioning equipment for buildings. However once the systems and equipment are in place, their proper operation and maintenance are required to ensure acceptable indoor environmental conditions at minimum energy consumption. In reality, however the attention given to building operation is sometimes limited by budgetary constraints and understaffed maintenance organizations. Consequently, some buildings are operated in a use until it fails or use until the occupants complain mode [6]. These operating modes minimize maintenance costs but only for the short term. In the long run such modes may increase overall costs because equipment lifetimes can be reduced by poor maintenance.

Automatic control of the HVAC system is required to maintain desired environmental conditions .The method of control is dictated by the requirements of the space. The selection and the arrangement of system components are determined by the method of control. Controls are necessary because of varying weather conditions and internal loads. The operation of the HVAC system is influenced by the atmospheric conditions, the operating characteristics and capacity limitations of each element in the system and also by the state of air in the conditioned space through the control system and through addition of return air into the system. The importance of the accounting for the characteristics of each component as well as the interaction between the HVAC system and the conditioned space can therefore not be stressed enough.

2.1.3 Types of HVAC Systems

A Variety of HVAC system is found in office buildings that differ from each other according to the building size, occupant activities, building age, geographic location and climatic conditions. ASHRAE has categorized the air-handling unit systems as all-air system, all-water system, air-and-water system, or as packaged commercial and office buildings as discussed in the subsequent sections is essential to recommend strategies for redemption. HVAC systems could also be classified according to their energy efficiency as highly efficient, moderately efficient or generally inefficient.

Variable Air Volume (VAV) Systems

It is a type of all-air system, which provide cooling and heating through the air supplied by the system. A fan controller in the air-handling unit compensates for reduced cooling demand in the occupied spaces by reducing the air volume in the system. The airflow is generally regulated through a variable speed controller. The room thermostat will regulate the reheat coil control valve and the volume damper position to satisfy the room requirements. Economizer cycles are often found on these units [8]. In a variable air volume (VAV) system with 100 % outdoor air, the cooling need in the building is satisfied with a certain air flow at a certain supply air temperature. To minimize the system energy use, an optimal supply air temperature can be set dependant on the load, specific fan power (SFP), chiller coefficient of performance, outdoor temperature and the outdoor relative humidity.

A variable air volume (VAV) system satisfies the health criterion by supplying a minimum amount of air flow based on national regulations and standards. There are a number of reasons for using VAV systems for indoor climate control. **Hung** [9] studied the performance of flow controllers in VAV systems. By simulations and field measurements, they found that the flow controllers were able to provide a stable zone air temperature. They also found that furniture and the zone interior surface stabilizers the zone air temperature dynamics.

Inoue and Matsumoto [9] have made energy analysis of the VAV system and compared it with other systems such as dual duct constant air volume (CAV) and two-pipe induction unit. Many VAV systems supply a constant air temperature and return a part of the extracted air to the HVAC unit and then to the supply air systems (return air). The reason for that is to decrease the power requirement and the energy use when the outdoor temperature is higher than the exhaust air temperature. VAV systems that use 100% outdoor air are installed in order to increase indoor air quality when there is a cooling need and to decrease energy use by only supplying air when needed. Hittle [9] pointed out that most VAV systems do not include any heating function in the main air - handling unit.

Variable -Air-Volume with Reheat

A VAV-RH system as shown in Figure 2.1 is a multi-zone system, where the supply air temperature is kept constant. , and the volume of air delivered to each zone is varied according to the load fluctuation in the zone. The thermostat in each zone modulates the terminal damper, allowing conditioned air into the zone to maintain the set point temperature [10].

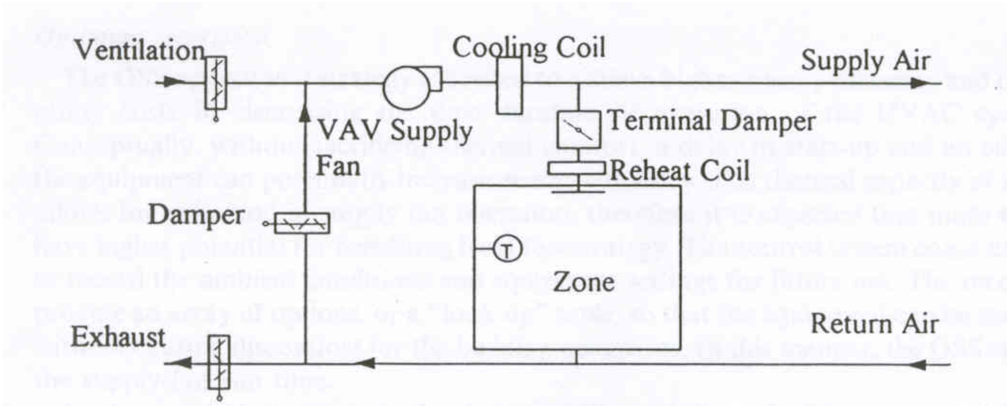

Figure 2.1: Variable air volume reheat System [10]

The static pressure builds-up in the distribution duct work as the terminal damper closes is used to modulate the VAV supply fan inlet vanes. If the modulating terminal damper is pre-set to allow for a minimum amount of cooled air into the zone for the purposes of ventilation requirements, some means of reheating is required to avoid over-cooling. The reheating can be accomplished by means of a coil placed down stream of the VAV damper (VAV-RH).

Constant Air Volume Systems

Single-duct constant volume systems change the supply air temperature in response to the space load while maintaining the constant airflow. This is the simplest of all-air systems that consists of a supply unit serving a single-temperature control zone [8]. It could be shut down when not required without affecting the operation of adjacent areas. Constant air volume systems could also be designed as multi-zone systems with or without provision for reheat.

It provides more space control for areas of unequal loading. The conditioned air is supplied from a central unit, generally at a fixed cold air temperature, which can be varied so as to reduce the amount of reheat required and the associated energy consumption.

The CAV-RH system as shown in Figure 2.2 is a multi-zone system and uses a central supply fan to provide a constant volume of conditioned air to the reheat coils of multiple zones. Terminal heating coils are controlled by the individual zone thermostats to provide reheating for the purposes of maintaining the zone temperatures [10]. The main supply fan continues operation during all scheduled occupied hours. Because the demand for most zones is cooling rather than heating, a constant volume of air at the design cooling supply temperature is distributed to all zones. The building load computation for this system is based on the peak load. The supply air temperature is fixed by the user and the design air flows are computed, based on the peak load for each zone. During occupied hours and when zone cooling load is not at a peak, the required zone temperature is maintained by means of reheat coils. During unoccupied hours, a night set-back temperature is specified and the system operates in the same manner.

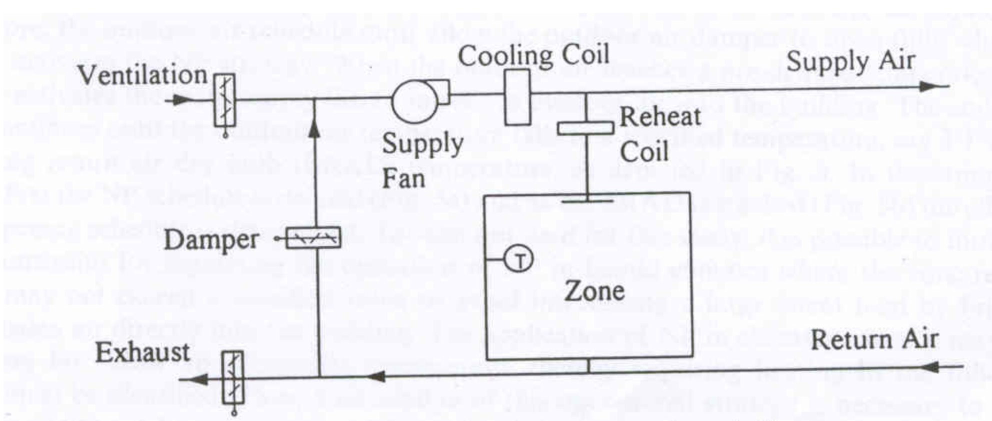

Figure 2.2: Constant air volume reheat System [10]

Heat Recovery System

There are several types of heat recovery or heat reclaim systems used in commercial institutional and industrial buildings [11]. Depending on the major application at the source on the waste heat and its place of use (heat sink), heat recovery systems could be broadly classified as: process -to-process, process-to-comfort; comfort-to-process; and comfort-to-comfort. The process in this type of classification could be that in a power generation, cogeneration or steam generation system; internal combustion engine and /or turbine drive; cooling of engines or compressors; or any other industrial or commercial process that offers a source of waste heat and is not directly part of the HVAC system providing comfort in the building. A comfort to comfort heat recovery system is also called internal source heat recovery system. Internal source heat recovery systems could be further classified depending on whether the operating cycle of the system is vapor absorption or vapor compression. In most internal source vapor compression heat recovery systems, water is the primary heat transfer fluid delivering comfort to various zones of the building. Significant annual HVAC energy savings and cost savings may be realized in commercial, industrial or institutional buildings by using the most viable heat recovery system.

Split Systems

As the name indicates, these systems are "split" into two, the air-handling units located inside the building and the condensing units located outside. Generally, air-cooled condensing units are used in the Eastern province of Saudi Arabia. These systems are very popular in low-rise commercial buildings and office buildings because of their lower cost and ease of installation. These Systems may operate with or without distribution ductwork.

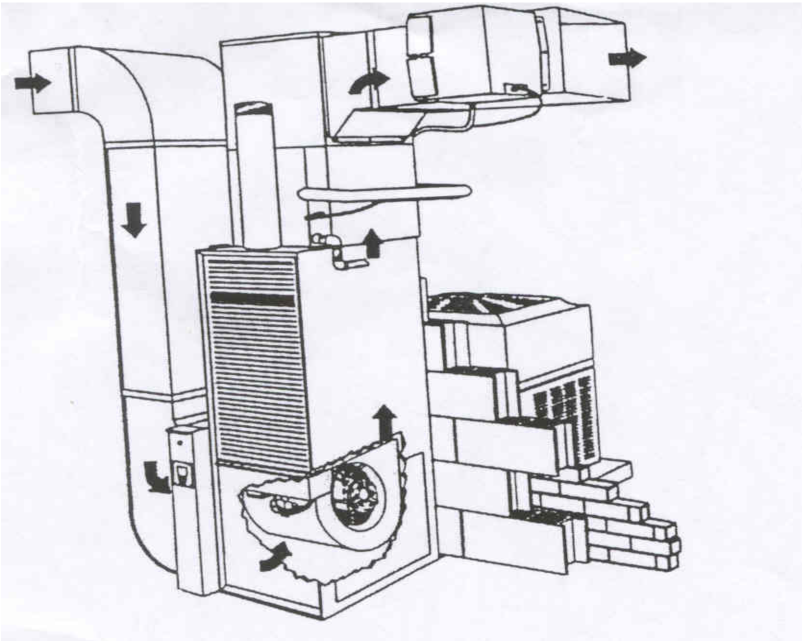

Figure 2.3: Split System [8]

2.1.4 Chillers

A chiller is a refrigeration system that cools water. Air conditioners and dehumidifiers condition the air while a chiller, using the same refrigerating operations, cools water, oil, or some other fluid. This chilled solution can be used to cool a wide range of operations.

Centrifugal chillers are used for cooling large buildings in a centralized air conditioning system. There are other types of chillers using screw compressors and reciprocating compressors. These are usually smaller in size. Basically, centrifugal chillers use centrifugal impellers to move the refrigerant within the chiller circuit. As with any refrigeration circuit, there must be a compressor, a condenser, an expansion device, and the evaporator. In the case of the centrifugal chiller, the impeller is the compressor. Rotating at very high speeds, it is capable of pressurizing the refrigerant gas so as to increase its temperature. Because the pressure is so dependent on the efficiency of the impeller of the compressor, the impeller is very carefully designed to match the system. The clearances between the impeller and the housing at the mouth ring (impeller suction) are made very small so as to reduce leaks back to the discharge. Centrifugal chillers are usually designed for low-pressure refrigerants like R-123a. These chillers sometimes surge when running, and they are very sensitive to sudden changes in loads. Therefore modern centrifugal chillers make use of electronic microprocessors to control the various parameters and timing in order to run smoothly.

Inefficient chillers can waste significant amounts of electricity, and even modest improvements in efficiency may yield substantial energy savings and attractive paybacks. However, it is important to select chiller efficiencies carefully because buying a chiller that is too efficient can raise first costs so high that the investment may not yield a reasonable payback period. It is also important to remember that chillers are actually part of a complicated system, and any inefficiencies or over-efficiencies in pumps, cooling towers, and controls also have the potential to waste as much, if not more, money than the wrong chiller. To maximize cost-effectiveness, it is recommended that the entire chilled water system should be analyzed in addition to exercising care in specifying the efficiency of the chiller itself. These chillers are available in sizes ranging from 70 to 2,500 tons factory-assembled and up to 9,000 tons field-assembled.

There are three types of electrical chillers using centrifugal, reciprocating or rotary compressors. All these chillers use mechanical vapor compression cycle. Chillers with centrifugal compressors have capacities in the range of 300 kW to 25000 kW (85 to 7000 tons) [25]. For capacities above 4500 kW (1250 tons), the centrifugal compressors typically field erected. Two or more reciprocating compressors can be used under part-load conditions to achieve higher operating efficiencies. The most conventional rotary compressors are the screw compressors that can have several configurations. The capacity of the rotary chillers can range from 3 kW to 1750 kW (1 to 500 tons).

The performance of a chiller is measured in two ways i.e. capacity and efficiency. Capacity is the total refrigeration capability of the chiller. Efficiency is the measured as the energy out per energy input. Some chillers that may be efficient at full load are not nearly as efficient at partial load, while other chillers maintain their efficiency at partial loads and some others actually increase in efficiency at partial load [1]. Since chillers operate so often at partial load, the part-load efficiencies should also be considered. To reduce the energy use of cooling systems, the energy efficiency of the equipment has to be improved under both full load and part load conditions.

In the US commercial air conditioning sector, centrifugal chillers account for 70% of the total installed cooling capacity which is estimated at 211 106 kW (i.e. 60 tons) [25]. In last 20 years, the improvement in the energy efficiency has been significant for centrifugal chillers. It can be cost effective to replace an existing chiller with a new and more energy efficient chiller. In recent years, significant improvements in the overall efficiency of mechanical chillers have been achieved by the introduction of two compressor reciprocating and centrifugal chillers and variable speed centrifugal chillers.

2.2 Thermal Comfort in Office Buildings

Buildings were first designed to shelter human beings from the harmful environment and the dangers surrounding them. At that time, little attention had been given to comfort with human comfort. The HVAC industry wants to sell a good indoor climate that means at least thermal comfort. To provide such an indoor climate, industry needs to know what good means. According to the ASHRAE definition, thermal comfort means "that condition of mind which expresses satisfaction with the thermal environment" [13].

A healthy young man at rest, wearing only trunks was exposed to different environmental temperatures. Average skin temperatures and central temperatures measured at the tympanic membrane were plotted against the environmental temperatures. In this case the threshold temperatures were 34^{0}C for the skin and 37^{0}C for the brain [30]. The heat loss from man in thermal comfort essentially consists of convection and radiation.

Draught problems are often the reason for low acceptance of HVAC equipment. Physical investigations showed that the correct physical quantity to judge air movement is the convective heat transfer coefficient which is the measure for the combined effect of mean velocity and turbulence intensity of air movements [14]. In modern offices, increasing numbers of computers often necessitate additional cooling of the air. An alternative to avoiding draught problems is panel cooling in combination with source ventilation .On the other hand; cooling panels can cause thermal discomfort by too high long-wave radiation. This means the assessment of the indoor air temperature alone is not sufficient. In addition, temperatures of the surrounding surfaces, their distances to man as well as their size and emission rate are to be considered too.

2.2.1 Factors affecting thermal comfort

Controlling and maintaining comfort inside buildings mean rather taking care of those factors that lead to discomfort. In fact, numerous factors do affect comfort; however the most important of them are briefly mentioned here.

Clothing

An individual can alter his or her comfort conditions through adding or subtracting clothing with regard to the indoor situation. Based on researches carried out by energy investigators working at Kansas state University, it has been proved that the most comfortable condition for subject wearing light clothing suitable for office wear (0.4-0.6 clo) [15] corresponds to an air velocity of less than 35ft/min and air temperature of 24^{o}C at 50% relative humidity.

Mean radiant temperature (MRT)

Another factor which affects comfort is the mean radiant temperature (MRT). It is defined as the uniform temperature of an imaginary black enclosure with which a person also assumed to be a black body, exchanges the same heat by radiation as in the actual environment. In other words, MRT is the average of all room surfaces weighed according to emissivity [15]. The great importance of the MRT comes from that the radiant heating or cooling ability of any surface must be calculated in the context of its area in proportion to the area and temperature of other surfaces in the room.

To show the practical use of MRT in determining comfort zones, it is noteworthy to realize that with a still air temperature of 32^{o}C and MRT of 19.4^{o}C required to achieve comfort at 0.5% clo, an equal sensation of comfort with 27^{o}C air temperature is achieved with a ventilation air speed of 20 fpm or 1m/s at 4.0 clo.

Relative Humidity

Relative humidity (RH) is the third important factor that affects comfort. RH basically is the amount of water vapor held in the air as a percent of the maximum amount of water the air can hold at a specific temperature and pressure. It has been found out that in winter, a relative humidity of 30% seem suitable for comfort. In summer, by contrast and a relative humidity of 50% sound ideal to accomplish comfort [3]. As relative humidity decreases from 50% to 20% or visa versa, the human body will not actually detect differences in comfort. Nevertheless, in cooling seasons the body feels uncomfortable until the relative humidity (RH) reaches up to 60% or higher.

The conscious mind appears to reach conclusion about the thermal comfort and discomfort from direct temperature and moisture sensation from the skin-deep body temperatures, and the efforts necessary to regulate body temperatures. Some of the possible behavioral actions to reduce discomfort are altering clothing, altering activity, changing posture or location, changing thermostat settings, opening a window, complaining or leaving the space.

Human Thermoregulation

Insufficient heat loss leads to overheating also called hyperthermia and excessive heat loss results in body cooling also called hypothermia. Skin temperature greater than 45^{o}C or less than 18^{o}C causes pain [13].Skin temperatures associated with comfort at sedentary activities are 33^{o}C to 34^{o}C and decrease with increasing activity [13]. In contrast internal temperatures rise with activity. The temperature regulatory center in the brain is about 36.8^{o}C at rest in comfort and increases to about 37.4^{o}C when walking and 37.9^{o}C when jogging. An internal temperature less than about 28^{o}C can lead to serious cardiac arrhythmia and death and a temperature greater than 46^{o}C can cause irreversible brain damage. Therefore, the careful regulation of body temperature is critical to comfort and health.

Conditions for thermal Comfort

Studies by Rohles and Nevins (1971) and Rohles (1973) on 1600 college age students revealed correlations between comfort level, temperature humidity, sex, and length of exposure (13). The thermal sensation scale developed for these studies is called the ASHRAE thermal sensation scale:

+3	+2	+1	0	-1	-2	-3
Hot	Warm	Slightly warm	neutral	slightly cool	cool	cold

Current and past studies are periodically reviewed to update ASHRAE Standard 55 [3], Thermal environmental conditions for Human occupancy. This standard specifies conditions or comfort zones where 80% of sedentary or slightly active persons find the environment thermally acceptable. The warmer and cooler temperature borders of the comfort zones are affected by humidity and coincide with lines of constant effective temperature. In the middle region of a zone, a typical person wearing the prescribed clothing would have a thermal sensation at or very near neutral. Comfort complaints about dry nose ,throat , eyes and skin occur in low humidity conditions, typically when the dew temperature is less than 0^oC.In compliance with these and other discomfort observations, ASHRAE Standard 55 [13] recommends that the dew point temperature of occupied spaces not be less than 2^oC.

Secondary Factors Affecting Comfort

Age

Because metabolism decreases slightly with age, many have stated that comfort conditions based on experiments with young and healthy subjects cannot be used for other age groups [13]. Fanger (1982), Langkilde (1979) conducted comfort studies in Denmark and United States on different age groups (mean age 21 to 84). The studies revealed that the thermal environments preferred by older people don’t differ from those preferred by younger people.

Adaptation

Many believe that people can acclimatize themselves by exposure to hot or cold surroundings, so that they prefer other thermal environments. Fanger (1982) [13] conducted experiments involving subjects from the United States, Denmark, and tropical countries. The latter group was tested in Copenhagen immediately after their arrival by plane from the tropics where they had lives all their lives. Other experiments were conducted for two groups exposed to cold daily. One group comprised subjects who had been doing sedentary work in cold surroundings (in the meat packing industry) for 8 hours daily for at least one year. The other group consisted of winter swimmers who bathed in the sea daily.

Only slight differences in both the preferred ambient temperature and the physiological parameters in the comfort conditions were reported for the various groups. These results indicate that people cannot adapt to preferring warmer or colder environments. It is therefore likely that the same comfort conditions can be applied throughout the world. However, in determining the preferred ambient temperature from the comfort equations, a clo-value that corresponds to the local clothing habits should be used. A comparison of field comfort studies from different parts of the world shows significant differences in clothing habits depending on, among other things, the outdoor climate (Nicol and Humphreys) [13]. According to these results, adaptation has little influence on the preferred ambient temperature. In uncomfortable warm or cold environments, however adaptation will often have an influence. People used to working and living in warm climates can more easily accept and maintain a higher work performance in hot environments than people from cold climates.

2.3 ENERGY CONSERVATION IN OFFICE BUILDINGS

Energy retrofits and the implementation of conservation measures can be a cost effective means of reducing energy consumption in buildings. Changing building HVAC operating strategies work equally well and can result in savings through reduced equipment purchases as a result of peak load saving [16]. Conservation refers to the protection or preservation of a valuable resource [17]. As we enter a new century, the single greatest contribution that can be made in the field of energy is conservation.

2.3.1 Energy Conservation in Saudi Arabia

A number of studies on energy conservation has been done out side and some research has been done in Saudi Arabia. In last two decades, electric energy consumption has increased rapidly from 3.7 million MWH in 1975 to 80 million MWH due to rapid development and rising population [19].

Al-Homoud [18] showed that 15%, 19% and 40% annual energy can be saved in large, medium and small office buildings through envelope thermal optimization in the Riyadh area. Similarly, for Jeddah, annual energy savings of 8%, 12 % and 24% can be obtained for a large medium and a small offices respectively. Ahmed et al (1994) reported an analysis of electric energy consumption for a supermarket in the City of Dhahran (a hot humid climate). They concluded that 38% of energy in commercial building studied is used for air-conditioning, 42% is used for appliances and the remaining 20% is used by lighting [19].

AL-Ajlian et al (1998) and Hasnain (1998) reported that the electric demand is very high during summer, mainly due to air-conditioning consumption which is high due to lack of thermal insulation in most of the buildings, as well as the absence of other energy efficiency measures and load management strategies [20]. Hasnain and Al-Abbadi (2000) estimated that 15% to 20% of electric utility peak load is consumed by central air conditioning in office buildings and large facilities in Saudi Arabia [21].

In Saudi Arabia, the growth of demand for electrical energy in the rapidly expanding towns, cities and industries, far exceeds the growth of the Power being made available. Recently the Saudi Consolidated Electric Companies (SCECO) is facing a shortage of electricity during the summer period mainly due to the high consumption of electricity in the air conditioning sector. Buildings in Saudi Arabia take the lion's share which could exceed 70% of the total electric energy use in country. For instance , in a supermarket (954m^2 air-conditioned floor area), located in the eastern province of the country , annually 38% of energy is used by air conditioning, 42% is used in appliances and the remaining 20% is used for lighting [21]. It is estimated that in a large commercial building, 60% of the energy is used in air-conditioning, 20% is used in appliances and the remaining 20% is used in lighting during the 8 months long summer period [21].

TES Economics in Saudi Arabia

A load leveling operating strategy using thermal energy storage (TES) system is most suitable in the kingdom. Chilled water is released during the day and is used in combination with "live" chillers to cope with the building cooling requirements. The installed chiller capacity is reduced to approximately 65% of that required if no TES is provided [21]. For new facilities, designing for energy conservation means incorporating a wealth of new techniques into building systems. For existing buildings, energy audit can be completed and use patterns analyzed to maximize energy use. For both new construction and renovation, there is considerable opportunity to improve the design and performance of buildings.

2.3.2 Energy Conservation in Office Buildings (global overview)

Buildings consume a significant portion of energy in the United States. Building consumes nearly half of all the energy in the country for heat, cooling, and power and it is estimated that nearly 30% of this consumption could be saved by energy conservation and/or sustainable building design and operations [17]. A large percentage of the total energy consumption of the world is utilized in buildings. Control has shown that buildings account for approximately 40% of the primary energy consumption in 15 countries including the US, the UK, Canada, France, New Zealand and South Africa [22]. These countries in turn accounted for 44% of the total world's primary energy consumption in 1980. According to other sources, more than 50% of all delivered energy in Europe and the United States can be associated with buildings. In the United Kingdom more than 60% of this is used to condition the indoor environment [30]. This means that more than 10% of all energy consumed in the world is expended by building air-conditioning systems. Energy efficiency of these systems is clearly of global importance. Energy inefficiency seems to be widespread in buildings and considerable scope for energy saving exists.

Studies have shown that in South Africa, approximately 20% of all available municipal electrical energy is used in commercial and office buildings. Further studies have shown that air conditioning is responsible for a substantial 50% of this [23]. Overall energy conservation efforts could reduce the energy demand for air-conditioning in buildings by about 40% by the year 2005 [8]. Efforts to improve energy efficiency should therefore not only concentrate on the design of the air-conditioning system but also include the building itself. Any building and HVAC thermal design tool should thus address, in an integrated manner, both the building and the HVAC system together with its control.

The use of air conditioning may in many cases be avoided or reduced by making use of combined passive and mechanical environmental control techniques [36]. A design tool that can take into account both conventional HVAC system as well as the passive performance of the building will thus be of great value [18].

2.3.3 Operational Energy Conservation Measures

Use of Programmable Thermostat

One way to conserve electrical energy in the building is to change the cooling requirement of each zone after office hours on working and non working days. Programmable thermostat has the facility to set desired room temperatures for different periods of the day and for different days of the week. They offer a better solution than ON-OFF timers or manual shutdown. These types of thermostats can be programmed for the entire week within the range of 5^oC (9^oF) or higher offset condition during the period of no occupancy to save energy in the building.

The Controller

It may be used to realize any desired control strategy such as maintaining a given space temperature or perhaps running the HVAC systems intermittently to realize some form of energy savings. The operation of the controller can also be influenced by the atmospheric conditions such as temperature and perhaps even radiation, and any of the space or HVAC system variables such as temperature, pressure, humidity and flow rate. It may be used to control the operation of any of the elements of the HVAC systems such as damper and valve setting as well as fan speed and compressor cylinder unloading. The simulation of the actual performance of the controller is therefore an important part of a proper design tool.

Energy Cost

Annual energy cost can in general not be calculated by simply multiplying the total energy consumption with a per unit energy cost. Electrical energy for instance, is usually made up of some combination between consumption charges and demand changes. According to ASHRAE, the percentage of the total electricity bill attributed to demand may be as high as 70% [22].

Use of Single Water Pump

During the non occupancy period of the building in summer time and during the month of November to March, the building cooling demand can be met comfortably by a single chiller. The use of a single water pump with a higher chilled water temperature setting to $8^{o}C$ can be used satisfactorily. Operation of the system with one chilled water pump can reduce the motor power around 7KW (2.4Btu/h) [19]. There are additional advantages, such as reduction in pumping heat and improved chiller performance, due to the increased temperature of leaving chilled water.

Ice Thermal Storage

If cooling is generated and stored during low-demand nighttime (off-peak period) for later day (on-peak period) use, more peak capacity would be available for other uses, and nighttime capacity of the power plant would be fully used. In this way, on peak energy consumption will be shifted to off-peak periods. Hasnain in 1999 [4] explained that installation of off-peak ice thermal storage (ITS) based air-conditioning systems in new Saudi office buildings could reduce peak electric load by 20% and peak cooling load by 30%. Nevertheless, there are a few favorable conditions for ITS application in Saudi offices and large buildings.

Air by pass

Mathews, Botha, Arndt and Malan [23] conducted an investigation for comfort enhancement and energy saving potentials with new control strategies. The first energy savings retrofit option investigated was air-bypass to the AHU cooling coils. This system comprises damper control units fitted to the AHUs to regulate the portion of supply air to bypass the cooling coil. Currently, these units are fitted to the AUHs supplying five lecture facility zones and are either not operational or insufficient to efficiently regulate the mass flow rates applicable. The air by pass retrofit consists of the repair and upgrading of these units. The total yearly energy saving was achieved by 4.6%. This is clearly not substantial; however this retrofit being relatively inexpensive may be an option.

Setback Control

Setback control involves selectively relieving HVAC component set-points. A typical example would be the relaxation of return air temperature constrains from unoccupied zones. This could be implemented through the use of motion detectors. It can be viewed as an extension of the air-by pass system together with reset control. Return air set-points were allowed to drift between 16 and 27^{o}C when the zones were unoccupied [23]. A typical application would be the implementation of motion detectors. This range was chosen to assure that the lag period (time constant) of the system was insignificant enough not to influence comfort levels should sudden changes in thermal load occur. Retrofit simulation showed setback control to affect substantial annual energy savings of 60%.

Night Purge

The night purge (NP) operational strategy is designed to reduce building utility costs by means of exploiting the thermal capacity of the building and other air-borne pollutants caused by daytime building usage. During the unoccupied periods, when maintaining thermal comfort is not required, outdoor air is brought into the building to cool the building mass for offsetting the cooling load at the beginning of the occupied hours. As prerequisites for applying this energy -efficiency measure, therefore, the controller must be capable of monitoring the outdoor and indoor air-temperatures as well as controlling the supply fan. Furthermore, the outdoor air schedule must allow the outdoor air damper to open fully when the controller activates the NP strategy. When the outdoor air reaches a pre-defined temperature, the controller activates the main supply fan to introduce outdoor air into the building. The supply of the cool air continues until the outdoor air temperature falls to a specified temperature say 3^oF above the building return air dry bulb (BRAD) temperature [23]. In the simulation program, first the NP schedule is defined and as the BRAD is tracked, the effective damper opening schedule is determined. Though not used for this study, it is possible to introduce another constraint for regulating the operation of NP in humid climates where the zone relative humidity may not exceed a specified value to avoid introducing a large load by bringing moisture-laden air directly into the building.

The application of NP in climates where it may cool the building far below an acceptable temperature, thereby requiring heating in the following morning, must be identified. Thus, a simulation of this operational strategy is necessary to avoid consuming additional heating energy while attempting to provide more energy-efficient cooling. The temperature of air often drops quickly one or two hours before sunshine, and during many summer nights ,the outdoor temperature drops when the sunsets. The temperature of outdoor air is often low enough that the air handling units can purge the building of all the stored heat that accumulated during the day.

The night purge program monitors the outdoor and indoor temperature and, if conditions are favorable, open the fresh air and exhaust air dampers fully and purges the building of all excess heat [5]. This program often works so well that mechanical air conditioning may not be required until half way through the working day.

Optimum start/stop

The optimum start or stop (OSS) operational strategy is devised to achieve higher energy efficiency to reduce building utility costs by decreasing the time duration of operation of the HVAC system supply fan [23]. Conceptually, without sacrificing thermal comfort, a delay in start-up and an early shut down of the equipment can potentially increase energy efficiency. The thermal capacity of the building mass allows for reduction in supply fan operation, therefore it is expected that more massive buildings have higher potential for benefiting from this strategy. The control system could have the capability to recode the ambient conditions and equipment settings for future use. The recorded data would provide an array of options or a "look-up" table so that equipment can be started and stopped without causing discomfort for the building occupants. In this summer, the OSS strategy minimizes the supply -fan run time.

In the simulation program, the desired OSS operation schedule is specified by means of two time-windows during which the optimum start and stop of the fan is to be applied. This schedule must be in accord with a previously –defined building operation schedule. The normal time of operation for the supply fan is from 5a.m to 6p.m. The OSS schedule controls the supply fan operation and determines how much later than 6a.m, the fan can be started within the optimum Start window (2 hours), and how much earlier than 6a.m the fan can be stopped within the optimum Stop window (2 hours). Because the supply fan can only be stopped and not started by the OSS controller, the main supply fan operation time must include the time-windows specified for the OSS operation.

For the hourly simulations, the number of minutes needed for the supply fan to bring the building return air dry bulb (BRAD) temperature up or down to the set point temperature is estimated by the OSS controller based on recorded performances from previous days. If this value is greater than or equal to the number of minutes remaining in the optimum start period, the fan is started. If the number of minutes is less than 1 hour, the fan is turned on for a fraction of the hour to maintain the set point temperature. Because the optimum start controller estimates the time needed for start up, the accuracy of the estimates decreases if longer optimum start time-windows are specified by the user. For the optimum stop, the supply fan is stopped if the BRAD temperature does not fall below the heating set point or rise above the cooling set point. In a similar way to the NP strategy, it is possible to constrain the OSS strategy by means of an offset between the BRAD and the set point temperatures.

An optimum start/stop program monitors outdoor and indoor temperatures and turns the equipment on at the optimum time to save energy [5]. Optimum stop time is often incorporated to shut down the equipment before the occupants leave but not so early that the building becomes uncomfortable before the unoccupied mode of operation.

2.3.4 DESIGN RELATED MEASURES

Occupancy sensors

Studies have shown that in many cases, offices are not occupied for the majority of the working day, although lighting and air handling for those offices are maintained throughout. With the use of occupancy sensors, the energy associated with lighting and conditioning these offices during unoccupied periods could potentially be eliminated. The use of occupancy sensors to reduce air handling and lighting energy usage for only the office areas simulated by multiplying the DOE-2 office occupancy schedule defector by 70% , 50% and 30% to represent these different occupancy levels [16]. The use of occupancy sensors for reducing air handling and lighting energy results in very significant savings but there is of course a capital and maintenance expenditure associated with implementing this measure.

Cold deck temperature set point reduction

A common way of reducing fan energy in dual systems is to reduce the set-point temperature of the cold deck which reduces the air quantity required to meet the space loads. This type of energy conservation measure was simulated for the agriculture building by reducing the cold deck set-point temperature. Reduced air handling energy requirements account for the modest saving in electrical fan energy.

Dead band programs

Dead band programs set the heating and cooling design temperatures so that they are not separated by a dead band in which neither heating nor cooling is required [5]. For example in an office set at 18^oC for heating and 25^oC for cooling there is a 7^oC dead band The temperature in the dead band is allowed to drift and no energy except fan power for fresh air is consumed by the HVAC system.

Unoccupied-period programs

A typical office building has set occupied and unoccupied periods for instance occupied from 8am to 6pm and unoccupied from 6pm to 8am. Office buildings are occupied by the majority of the workers for only about 48 hours per week. For the rest of the time the building should be set to unoccupied set back mode turning down the heat to 15^oC request to have their area heated or cooled in the occupied mode if they wish to work late or on weekends. Unoccupied period programs make the application of zoning and override capabilities of a control system worthwhile. Most override modes of operation last for three hours, then returns to the unoccupied mode or returns to override mode for another three hours. Energy management systems incorporate programs that address all of these areas of energy consumption.

Careful control of HVAC systems can result in significant energy savings. For example electricity can be saved by reducing pump or fan operation time and intensity. Reduction of outside air intake will save on the energy used by cooling and heating equipment [5]. Economizer sections on air handling units can use outside air free cooling which reduces the load on the cooling equipment.

2.4 COMPUTER SOFTWARES FOR BUILDING ENERGY ANALYSIS

Energy consumption to provide thermal comfort conditions, especially in hot and humid areas is tremendous. Ways to reduce and save energy are indeed possible and needed. The simulation of HVAC energy consumption in buildings is of considerable interest and benefit for both engineers and architects. Energy simulation programs can be used to analyze cost effective energy conversation measures before the building is built or modified. There are both open type simulation programs and proprietary programs.

The power consumed in providing thermal comfort conditions in buildings in hot and humid areas is tremendous. In some of the hotter areas in Saudi Arabia (Jeddah on the Red Sea, for example) more than 50% of the electric energy produced goes to providing comfort conditions in buildings. [24]. Energy simulation in buildings offers a valuable tool for engineers and architects to evaluate building energy consumption before the building is constructed. It can also be used to study the impact of building modifications on building energy use. Alternative designs or materials can immediately be evaluated to see how much they effect the annual energy consumption. This could lead to selecting energy efficient designs without sacrificing human comfort. All this may be done in a relatively short period of time on a home PC. Over the years, large and complex energy simulation computer programs have evolved. These programs are mainly of two types: open source code and proprietary programs [31]. It is intended in this review to focus on the open source type program, to give a broad idea of the main components of these programs, to identify some of the problems encountered by new users and to comment on new trends.

There are two basic levels of energy analysis tools [18]. Simplified energy calculations and detailed energy calculations. Simplified energy calculations are represented by the degree-day method suitable for energy consumption estimates relating to small buildings and the modified-bin-method, which can be used with better accuracy for estimating the energy consumption of larger buildings, detailed energy calculations and for applying hour by hour energy simulation. Such programs used to simulate the energy consumption in a building and its sub systems for every hour of an average whether year. They offer detailed analysis of a building's energy use accounting for all factors such as building schedule, occupancy as well as building mass. They also offer life-cycle cost analysis with different output options depending on the individual program. Some of the well-known simulations programs are briefly presented below.

1. DOE-2 It. was developed at the Lawrence Berkeley National Laboratory (LBNL) by the US department of Energy and is widely used because of its comprehensiveness. It can predict hourly, daily, monthly and /or annual building energy use. DOE-2 is often used to simulate complex buildings [25]. Typically, significant efforts are required to create DOE-2 input files using a programming language called Building Description Language (BDL).

2- BLAST (building loads analysis and systems thermodynamics) program enables the user to predict the energy use of a whole building under design conditions or for long term periods, The heating/cooling load calculations implemented in BLAST are based on heat balance approach (instead of the transfer function technique adopted by DOE-2) Therefore, BLAST can be used to analyze systems such as radiant heating or cooling panels that cannot be adequately modeled by DOE-2.

3- ENERGY PLUS builds on the features and capabilities of both DOE-2 and BLAST. Its first version is expected to be issued` in year 2000. ENERGY plus uses new integrated solution techniques to correct one of the deficiencies of both BLAST and DOE-2 the inaccurate prediction of space temperature variations. Accurate prediction of space temperatures is crucial to properly analyze energy efficient systems. For instance, HVAC system performance and comfort are directly affected by space temperature fluctuations. Moreover ENERGY plus has several features that should aid engineers and architects to evaluate a number of innovative energy efficiency measure. These features include:

- Free cooling operation strategies using outdoor air,
- Realistic HVAC systems controls,
- Effects of moisture adsorption in building elements.

4- TAS is software for the thermal analysis of buildings. TAS includes a 3D modeler, a thermal/energy analysis module, a system/controls simulator and a 2D CFD package [26]. There are also CAD links into the 3D modular as well as report-generation facilities. It is a complete solution for the thermal simulation of a building and a powerful design tool in the optimization of building's environmental energy and comfort performance.

5- HAP (1.17or 3.05) is software developed by carrier and is currently used to calculate cooling and heating loads in order air conditioning systems in building with multiple zones (up to 20 zones) It can also perform seasonal and annual energy analysis and evaluate potential energy savings from several energy conservation measures.

6- TRNSYS provides a flexible energy analysis tool to simulate a number of energy systems using defined modules. A good knowledgeable of computer programming (FORTRAN) is required to properly use TRNSYS simulation tool.

DOE PROGRAM OBJECTIVES

Decrease the amount of energy require the program is formulated around increasing energy use efficiency developing energy substitution options (such as coal for natural gas.) and providing technologies, methodologies, and processes that do satisfy human needs. All activities undertaken are directed at maximizing the effectiveness of energy use within a framework that is both economically and environmentally sound. Activities that accelerate and complement private sector efforts and faster the acceptance of energy-saving technology in the residential and commercial sectors are pursued as well.

2.5 CASE STUDIES

Case Study 1

Short monitoring campaign for heating and cooling purposes has been performed in 186 office buildings in Greece by a trained panel of engineers using standard reporting forms and an extensive questionnaire addressed to the building occupants [27].

The following information has been collected from each building:

1) General information about the occupants and the building.

2) General and specific information about the building envelop

3) Information about the heating, cooling and lighting systems.

4) Information about the office equipment.

5) The energy consumption of the building.

In parallel with the standard forms, a specific questionnaire was designed in order to collect information about the thermal comfort and the indoor air quality inside the office buildings. The opinion of the occupants regarding the thermal comfort inside the building during the heating and the cooling seasons was separately recorded. The seven steps of the thermal comfort scale proposed were used. A data has been created using the information recorded from all the buildings. The collected primary data have been analyzed in order to identify the energy characteristics of the office buildings in Greece and then assess the applicability, potential and limitations of some important energy conservation techniques and use of high efficiency energy systems.

Energy savings calculations are based on the assumption that the building operates inside the standard ASHRAE thermal comfort zones during the heating and cooling period. Also the visual comfort standards for office buildings are used.

Case Study 2

As a step toward exploring energy conservation opportunities in Saudi office buildings, a six story office administration building located in Riyadh was selected to conduct an energy audit [19]. its construction was completed in 1995.It is at latitude of 24:33 N degrees and longitude 46:43 E degrees with an elevation of 626m. This building has been in use since 1996 and is equipped with a number of different types of office equipment and lighting fixtures. The building air-conditioning system is composed of three air-cooled reciprocating chillers, three liquid distribution pumps and four air-handling units(AHUS).This paper reports measured values of actual electrical energy consumed by individual chillers, AHUs, different lighting systems, office equipment. And other associated electric appliances used in the building. The results show that daily air-conditioning energy represents 74% of the building's total electric load during the summer peak period. The other major measured electric loads are 11.4% for interior lights and 11% for office equipment [19]. Rescheduling of chiller for optimum performance use of energy-efficient lighting, and use of programmable thermostats are suggested to be incorporated in the building for energy and power savings.

Case Study 3

A 50,000 ft^2 single story elementary school and a 34000-ft^2 two-story office building in Georgia, U.S., were monitored to determine energy-use patterns affecting performance [28]. The project was undertaken by a building owner's representative and therefore represents an attempt to achieve goals that are of interest to a building owner. The emphasis was on short-term monitoring with portable equipment that is easy to install and remove. Electrical consumption of heating, ventilating, and air conditioning (HVAC), lighting receptacles and mainframe computers was each monitored separately. Monitored data were also recorded for gas consumption and outdoor temperature, humidity and solar radiation.

Monitored data were required to model certain input parameters for building simulations and to validate simulation output. Instruments were carefully selected for ease of installation and portability so they could be removed to different rooms and buildings. Most instruments were fairly easy to install and set up and high-quality data were collected. Retrieval and analysis of data were enhanced by software supplied with the instruments.

Often there is no substitute for actual monitored data, as when determining the energy savings after a retrofit, or when validating a computer model early in design. This case study describes some of the key elements in obtaining those data, including learning from other projects.

Case Study 4

A computer simulation using two multi room zones from an actual office building in Nashville Tenn was performed to quantify the energy savings potential inherent in the individual room temperature control design [29]. The building is occupied by the federal government employees and used as office space. The actual room data, including number of people, interior equipment, and lighting, were input into the program. Each multi room zone consisted of six rooms, with one MRZ being an external zone and the other being an internal .zone [29]. Schedules to simulate the internal load diversity were created that varied the occupancy of each room by the hour. These schedules took into account absences for vacations, sick leave, travel, training etc. At least one office was occupied at all times during the 12 hours day with the heaviest occupancy during the normal business hours.

Lights and computer equipment in each room used these same schedules assuming that they were turned off when ever the occupants left the room. The

HVAC systems were scheduled to operate from 7 am to 7pm, Monday through Friday. Thermostat settings and space temperature drift limits were also taken from general service administration regulations. These called for a 22.5^{o}C thermostat set point for heating. The building was allowed to drift between a minimum temperature of 20^{o}C and 24^{o}C during the off periods [29]. The computer simulations were run with three different types of HVAC systems to compare the variation of energy consumption.

The first run used a low pressure multi zone system with a single thermostat in room 4 of each zone. The second run used a medium-pressure VAV system with the same thermostat location as the multi zone calculation and single air valve for each zone. The final run used a low pressure VAV system with each room having a thermostat and air valve. All simulations used the same primary cooling and heating equipment-chilled water for cooling and hot water boiler for heat. Only the air system and thermostat parameters were changed among simulations. This provided an estimate of the energy savings potential of an individual room temperature control (IRTC) system. Using multi zone system as a base line, VAV system with MRZ control used more energy than multi zone system. This is because, the medium pressure VAV system running at full load uses more fan energy then the multi zone system due to the higher fan pressure and losses in speed control.

CHAPTER 3

ASSESSMENT OF BUILDING COMFORT CONDITIONS A QUESTIONNAIRE SURVEY

3.1 Introduction

Indoor environmental quality in office buildings refers to the provision of lighting comfort, acoustical comfort, thermal comfort for its occupants and avoidance of performance debilitation in the capabilities of office workers. The environmental quality in one office building would not necessarily be identical to the environmental quality in another similar office building in every detail but there are common factors that help determine the quality level of environmental comfort in almost all office buildings.

The ANSI/ASHRAE standard 55-1992 and the Thermal Environmental Conditions for Human Occupancy standard define an acceptable thermal environment with conditions in which 80% or more of the occupants will find the environment thermally acceptable [45].

A questionnaire survey is a good tool for the assessment of the occupant's satisfaction with the building. For this purpose, a questionnaire survey was designed and conducted. The questionnaire focuses on perceived attributes of the individual's work environment such as air temperature, air humidity, air velocity, lighting level, acoustical level and other environmental related issues.

3.2 Questionnaire Design

A questionnaire for the Al-Yaum office building was developed to assess occupant's satisfaction level with the indoor environmental conditions of their workplaces. This questionnaire was designed as detailed in Appendix D with the aim of acquiring information on the following aspects:

- General information on the assessed space such as floor number, age, type of place, location of workplace etc;
- Occupant's perception of work place environment such as air temperature, air humidity, noise level, lighting level and air movement;
- Other information such as the adequacy of ventilation, voice privacy, and presence of interior shading.

Hence, the questionnaire was distributed to occupants of all six floors of the building. The results from the questionnaire survey have been used to assess the thermal comfort and other workplace conditions.

3.3 Conducting the survey

3.3.1 Briefing

The occupants of the building were introduced to the objectives of the study and its importance in work environment. They were ensured that their identity would not be exposed. Also the higher administration was taken into confidence by making an information request (Appendix C) for easy movement in the building. It was also communicated that this study would come up with recommendations to improve their working environment and was encouraged to participate in the study by filling in the questionnaires that were made available in both English and Arabic.

3.3.2 Response to Survey

A total of one hundred and six (106) questionnaires were distributed to the building occupants. A total of seventy four (74) questionnaires were collected which represents 70% response rate. About one hundred (100) questionnaires were distributed in Arabic and only six questionnaires were distributed in English.

There were a total of eighteen (18) questions in each questionnaire. Initially, the response was not as good as expected but later most of the occupants came forward to provide their feedback by filling in the questionnaires. Initially, questionnaires were collected the following day or the day after their distribution because of the busy schedule of the occupants. Later, it was preferred to get them filled in the presence of the author so that if the occupants have any concern, it could be clarified instantly.

3.4 Questionnaire Analysis and Discussion

The questionnaire as illustrated in Appendix C was divided into three sections, namely general information about occupants and their location, thermal comfort assessment and other workplace assessment. First of all, the analysis of the questionnaire was conducted for the whole building and then the responses were analyzed for each zone separately.

As can be seen in Figure 3.1, about 78 % of the surveyed respondents have indicated that they are comfortable with air temperature while 18% indicated that they are sometimes uncomfortable with air temperature. All the surveyed respondents (100%) have indicated that they feel comfortable with air humidity and air movement. They also indicated that they feel no stuffy feelings. Most of the surveyed respondents (100%) showed great concern about thermostat location; they suggested that there should be a thermostat within their range for any temperature change.

About 66% of the surveyed respondents have indicated that they never feel any ventilation problem. On the other hand, 19% of the surveyed respondents have indicated that they feel inadequate ventilation for some time while another 12% of the surveyed respondents indicated that they feel a ventilation problem for all the time. About 79% of the surveyed respondents have indicated that their working productivity is not adversely affected due to thermal discomfort.

When asked about the impact of thermal discomfort on their job stress, 78% of the respondents indicated that they didn’t feel job stress due to thermal discomfort. All the respondents (100%) have indicated that they didn’t feel any complaints about the maintenance department and air-conditioning system. None of the surveyed respondents indicated that they had any pedestal fan at their workplaces. About 75% of the surveyed respondents indicated that they didn't feel warm during summer because their workplace is exposed to outside while 23% of the surveyed respondents have indicated their neutral response. Most of the surveyed respondents indicated that they had neither interior shading nor operable windows as shown in Figure 3.1.

Most of the surveyed respondents have indicated that they have adequate lighting at their workplaces and they didn't feel visual discomfort due to glare from lights. About 73% of the surveyed respondents have indicated that they don't feel lack of voice privacy while another 21% of the surveyed respondents indicated that they felt lack of privacy. About 98% of the surveyed respondents have indicated that they didn't feel discomfort from noise coming from equipments and other sources.

Thermal comfort conditions of the building were also analyzed floor by floor of the building. The analysis indicated that all the surveyed respondents are satisfied with air temperature, air humidity and air velocity. However, 44% and 17% of the surveyed respondents on the first and second floors indicated that they felt uncomfortable with air temperature for some period of time as shown in Figure 3.2 and Figure 3.3

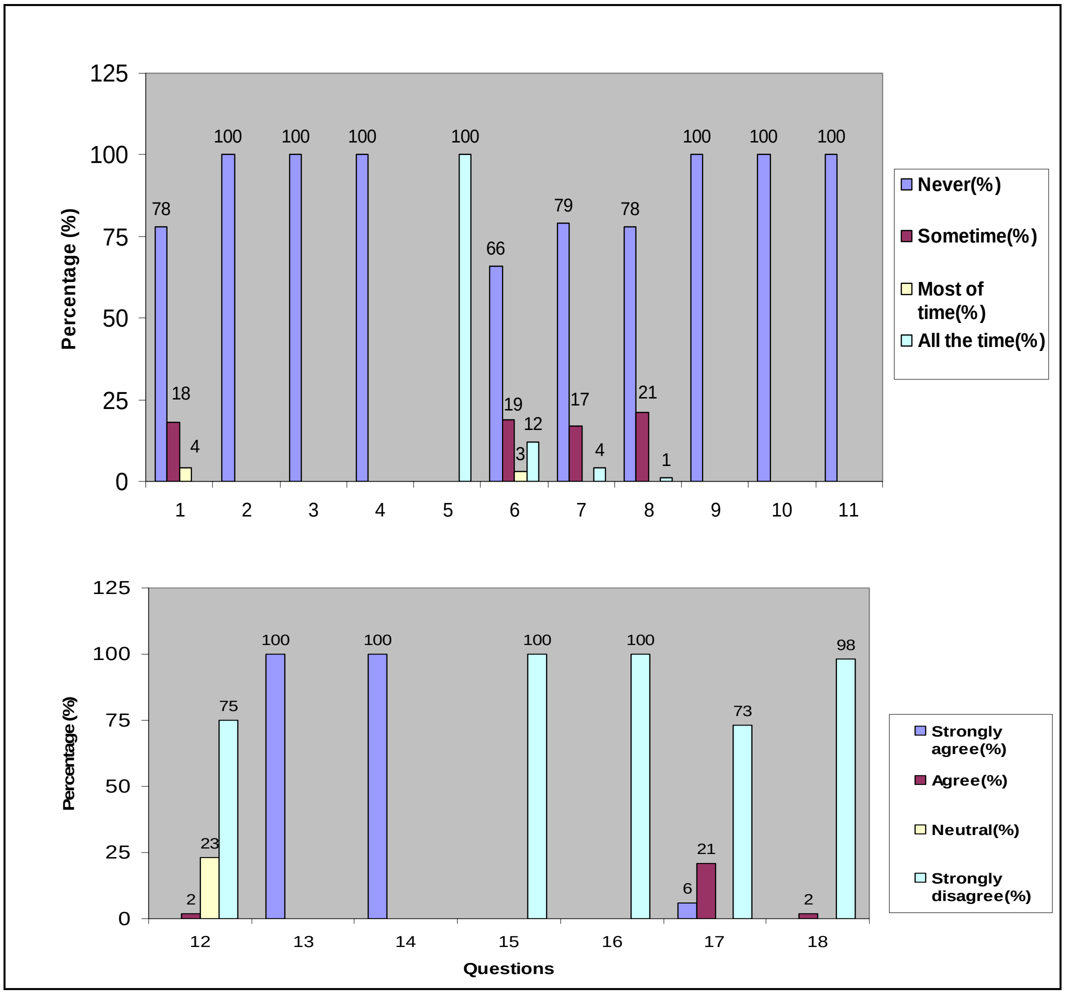

Figure 3.1: Response of surveyed occupants of the Building for thermal comfort conditions

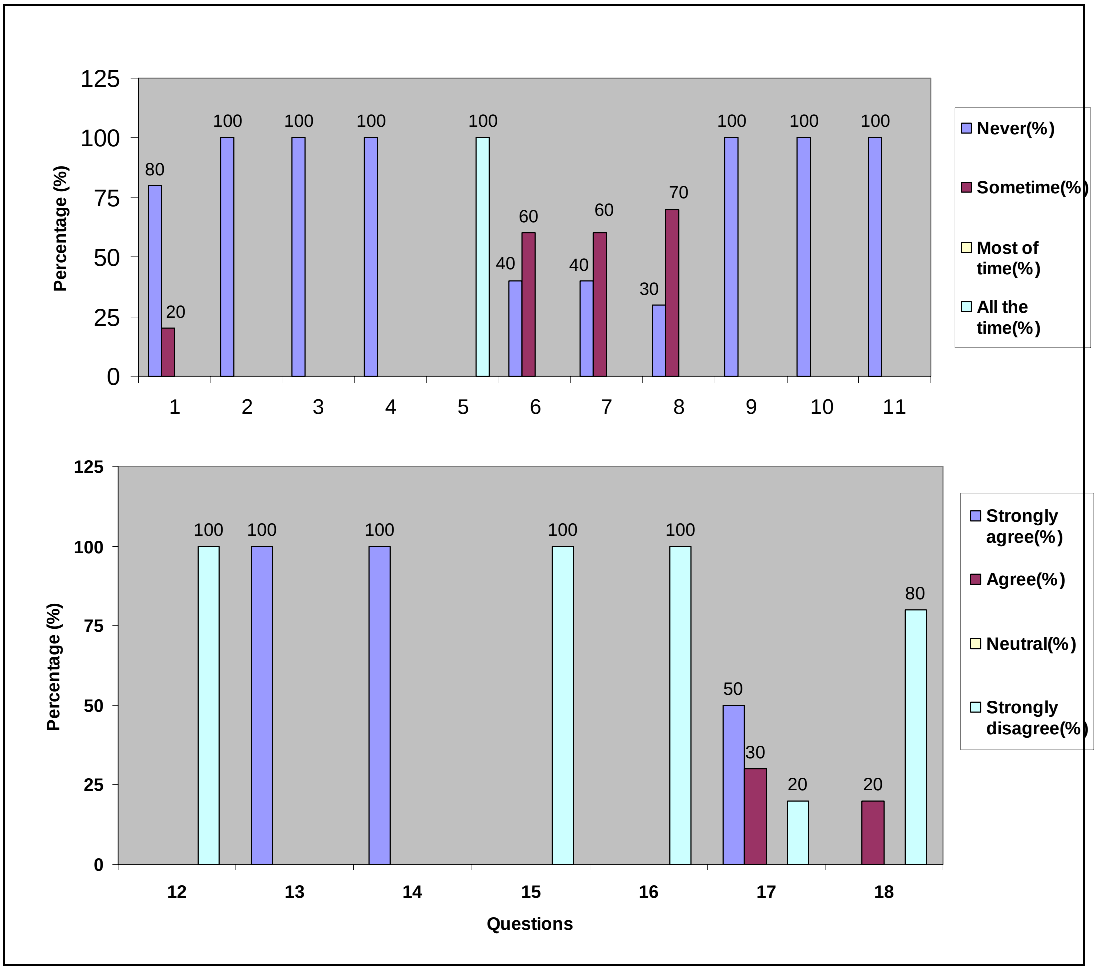

Figure 3.2: Response of surveyed occupants of the ground floor for thermal comfort conditions

As can be seen from Figure 3.2 to Figure 3.6, Most of the surveyed respondents indicated that they could not adjust thermostat for changing indoor air temperature and they added comments that they sometimes felt cold during working hours but they could not change the air temperature due to the unavailability of thermostat within their range.

About 60% of surveyed respondents on the ground floor, 50% of the surveyed respondents on the first floor and 53% of respondents on the second floor indicated that they felt inadequate ventilation for performing their work at some time as shown in Figure 3.2 and Figure 3.4.

Most of the surveyed respondents indicated that their working productivity was not adversely affected due to the thermal discomfort. However, 60% of surveyed respondents on the ground floor and 25% of the surveyed respondents on the first floor indicated that their working productivity was adversely affected due to thermal discomfort as shown in Figure 3.2 and Figure 3.3**.** About 70% of the surveyed respondents on the ground floor and 32% of the surveyed respondents on the first floor indicated that they felt job stress for sometimes due to the thermal discomfort.

Most of the surveyed respondents indicated their satisfaction with air-conditioning at their workplaces and they also indicated that they always got a quick response from maintenance department. All the surveyed respondents have indicated that they didn't feel warm at their workplaces during summer. However, 38% of surveyed respondents on the first floor, 17% of surveyed respondents on the second floor and another 15% of surveyed respondents on the fourth floor have indicated that they felt warm during summer at their workplaces as shown in Figure 3.4 and Figure 3.5 because their workplaces were exposed to outside.

As can be seen from the Figures 3.2 to 3.6, Most of the surveyed respondents on each floor indicated that they didn't have interior shading for windows to stop heat and they don't have operable windows for getting fresh air. Further more, most of the surveyed respondents indicated that they had not inadequate lighting at their workplaces and they didn't feel visual discomfort due to glare from the lights.

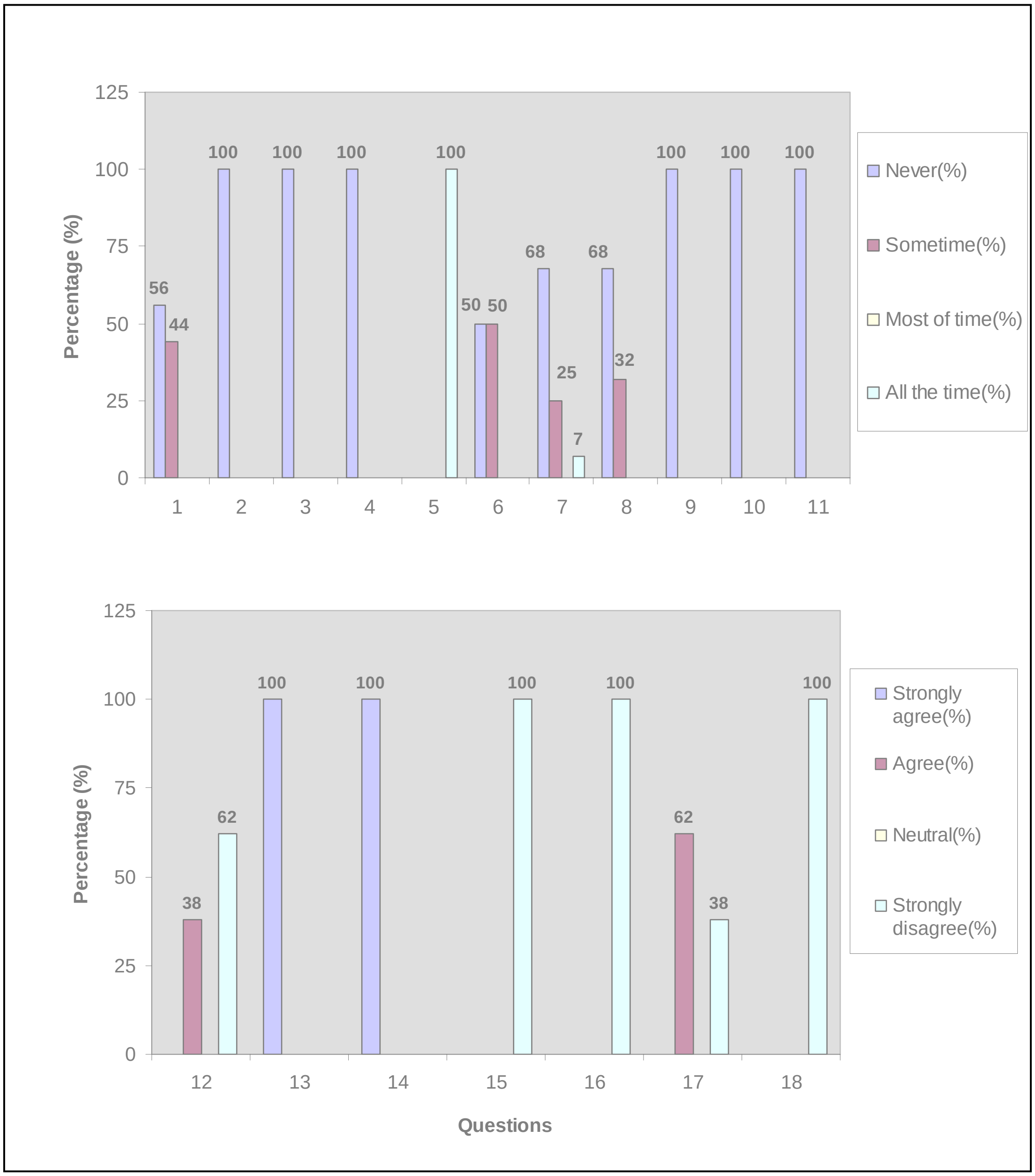

Figure 3.3: Response of surveyed occupants of the first floor for thermal comfort conditions

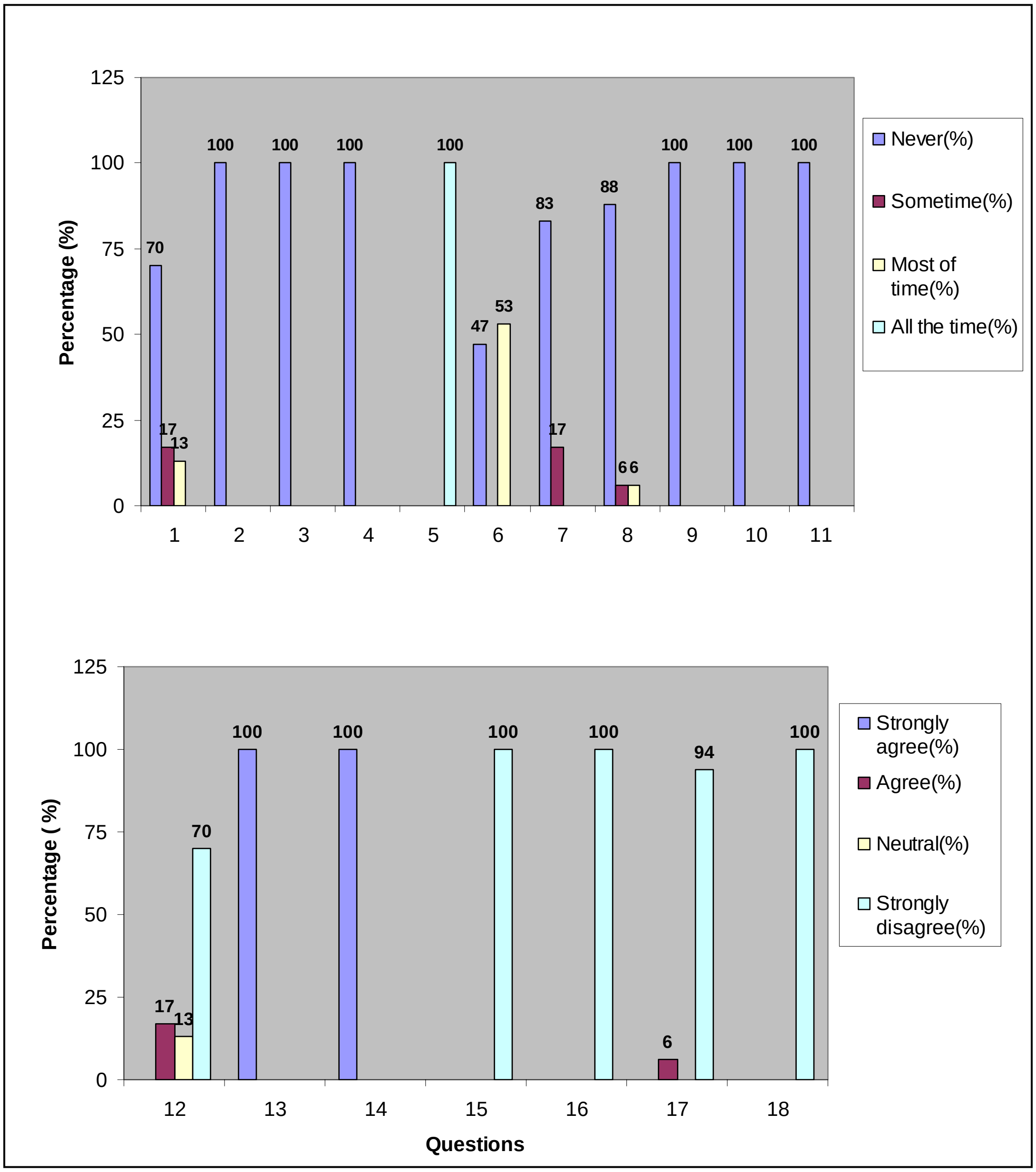

Figure 3.4: Response of surveyed occupants of the second floor for thermal comfort conditions

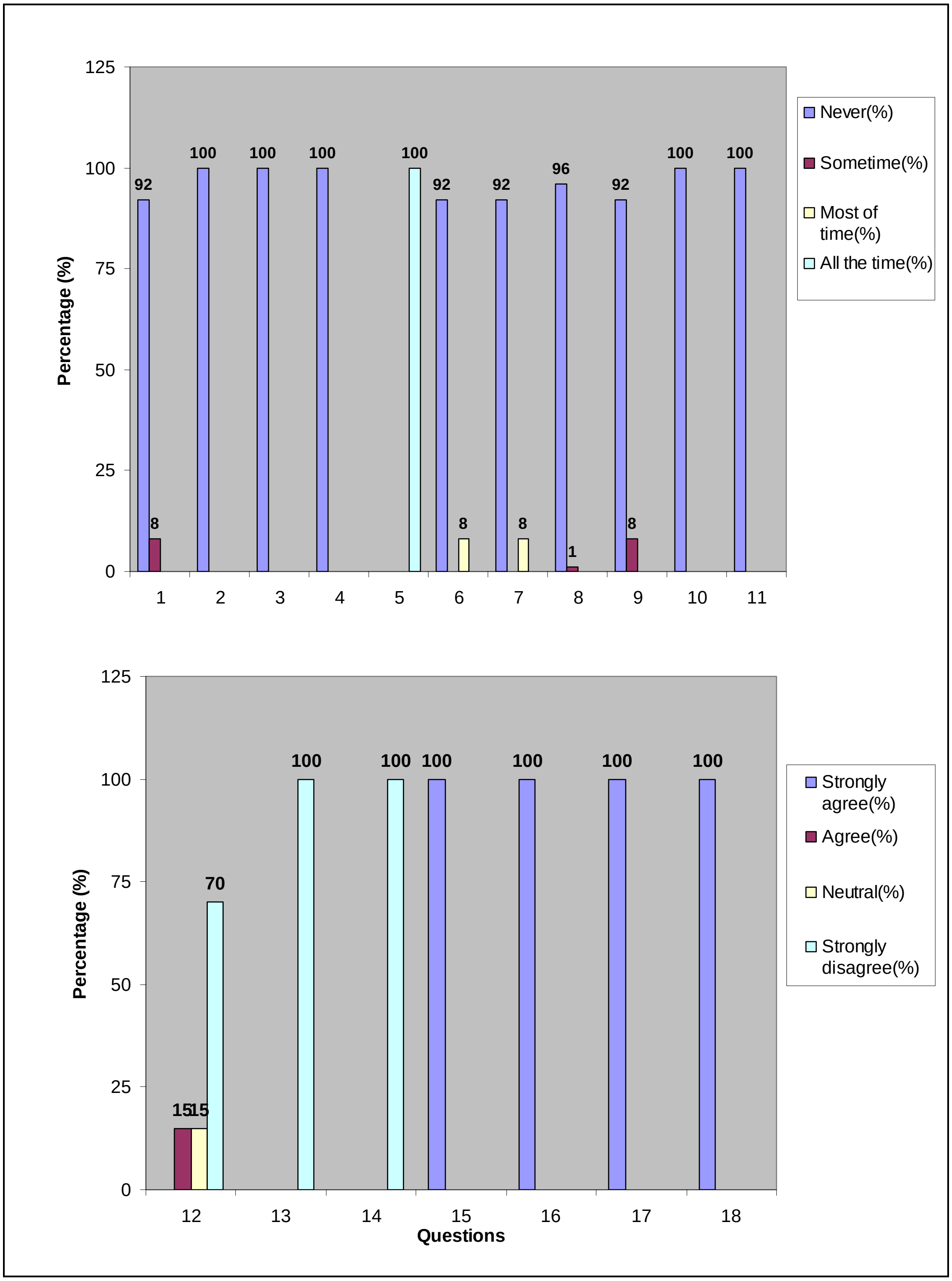

Figure 3.5: Response of surveyed occupants of the fourth floor for thermal comfort conditions

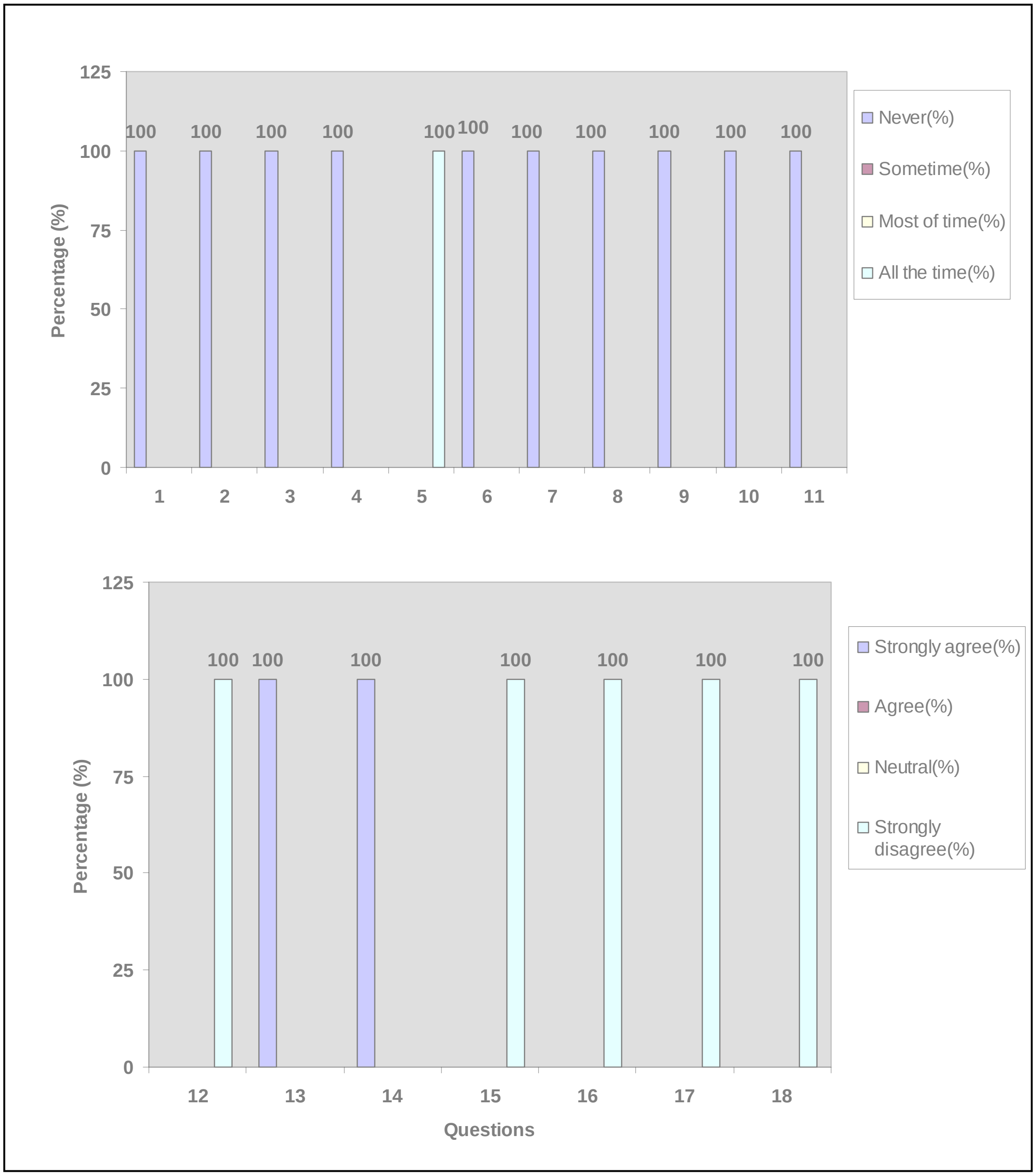

Figure 3.6: Response of surveyed occupants of the fifth floor for thermal comfort conditions

About 50% of the surveyed respondents on the ground floor and 62% of the surveyed respondents on the first floor indicated that they felt lack of voice privacy at their workplaces as shown in Figure 3.2 and Figure 3.3.

The results of the questionnaire analysis have indicated that most of the surveyed respondents have shown their satisfaction with thermal comfort and other workplace conditions. However, few problems have been found on some floors. More than 50% of the surveyed respondents on ground, first and second floors have indicated that they have inadequate ventilation at their workplaces. The reason could be the insufficient air movement and air distribution on these floors. According to ASHRAE standard [13], ventilation rate should be 7.5 l/s/person. The results also show that about 70% of surveyed respondents on the ground floor and about 30% of surveyed respondents on the first floor indicated that they felt job stress for some times due to thermal discomfort. There could be the indoor air temperature and humidity out of comfort range at these timings. About 38% of the surveyed respondents indicated that they felt warm during summer because their workplaces are exposed to outside. The reason for this could be the entrance of direct solar radiation from outside especially during August month and there is no interior shading available on the windows to stop heat coming from outside. About 60% of surveyed respondents on the first floor and about 30% of surveyed respondents on ground floor have indicated that they felt lack of voice privacy at their workplaces. There are open offices with glass and wood partitions and voice privacy could not be protected in these areas.

Conclusively, the results of the thermal comfort and other workplace assessment survey have shown that the majority of the occupants of the building are satisfied with thermal comfort and other workplace conditions except for some problems as mentioned above where the occupants of the building are not satisfied and have their reservations.

CHAPTER 4
HVAC SYSTEM AND THERMAL COMFORT ANALYSIS

4.1 Introduction

Buildings are designed and erected for people to serve as shelter and to provide them with a comfortable environment. In order to the enhance comfort and well being of the occupants of any building, thermal requirements are controlled with extensive and often complicated HVAC control systems. More specifically, office buildings to operate them comfortably in hot and humid climates such as those existing in Saudi Arabia need HVAC systems.

It is well-known that air-conditioning systems are among the major contributors to energy consumption in buildings. One important aspect of air-conditioning systems is the heating and cooling loads. Controlling and maintaining comfort inside buildings mean rather taking care of those factors that lead to discomfort. In fact, numerous factors do affect comfort and the most important of them are air temperature, air humidity and air velocity.

This chapter discusses the field survey results from the audit of the office building and performance related measurements of the major indoor environmental parameters of air temperature, air humidity and air velocity.

4.2 Walk through Audit

The intent of the walk through inspection was to acquire a good overview of building functions regarding building systems thermal comfort conditions and measuring different environmental parameters which include air temperature, air humidity and air velocity. It also helps in determining whether the zone temperature and humidity are within the comfort range as described in the ASHRAE standard [13] or not. The first step of the walk through audit was an initial assessment in which information about the building and its HVAC systems was gathered by the following means:

1 Interaction with the different representatives of the building which includes the building manager and operation and maintenance personnel. They were briefed about the purpose of the study and the information required.

2 Review of available engineering and architectural drawings. All drawings and specifications were carefully reviewed whenever possible to obtain with the following information:

- HVAC systems characteristics
- Supply Fan
- Chiller supply temperature
- Entering condenser water temperature
- Details of central plant (Cooling and heating management, schedule, time period)
- Building envelope characteristics
- Lighting
- Ventilation.

4.3 Field Measurements

Certain field measurements that are indicative of thermal comfort such as air temperature, air humidity and air velocity were taken. These measurements help to establish baseline conditions that could be compared with standards such as ASHRAE standard [13].

Different instruments have been used to collect data regarding air temperature, air humidity and air velocity. These instruments include the smart Micro Logger, Dickson Logger and Datamatrics. The smart logger and Dickson instruments were used to measure air temperature and air humidity on hourly basis and Datamatrics was used to measure air velocity in different places of the building.

4.3.1 Conducting the Measurements

Environmental measurements were carried out to assess the existing status of thermal comfort in the building. The following parameters were monitored to indicate the general performance of the HVAC system:

1 Zone temperature
2 Zone Humidity
3 Zone air velocity.

There were six floors in the building and each floor was divided into four zones. Each zone was cooled by a separate Air Handling Unit. Two types of instruments were used to monitor air temperature and air humidity for each zone. These instruments were installed in the office building for the summer months of June, July and August and for the winter months of November and December.A small description about each of these instruments is given below:

Dickson Loggers

Dickson loggers measure both temperature and humidity with its internal sensors [41]. Dickson Loggers don't have ON/OFF switch. Each Logger has adjustable sample intervals from 10 seconds to just over one day and parameters can be monitored that change frequently or cover extended periods without running out of memory.

Microloggers

Micro loggers are used to store space temperature and humidity with accuracy. Like Dickson instrument, Micro logger is Pocket-sized and self-powered, accurate and versatile instruments. There is no ON/OFF switch. Each Logger has adjustable sample intervals from one minute to 60 minutes [42]. Both instruments for measuring air temperature and air humidity were installed near the thermostat of each zone at all floors of the building except the third floor which was closed for unknown period of time. These instruments automatically stored hourly data for measuring air temperature and air humidity.

4.4 Field Measurement Analysis

This section deals with the analysis of building indoor conditions.The indoor air temperature and humidity was recorded and supply air flow for all zones of the building were measured. This analysis will help in finding the locations of the building where the indoor air temperature and humidity are out of the comfort range during summer and winter days.

4.4.1 Building Indoor Conditions (Temperature, Humidly and Air speed)

The environmental factors controlling thermal comfort include air temperature, air humidity and air speed. Temperature is perhaps the most important environmental factor that determines the perception of comfort. According to the ASHRAE standard [13], comfort zone is defined as if the temperature lies between 23^oC and 26^oC for summer conditions then it is acceptable for thermal comfort and for winter conditions if air temperature lies between 20^oC and 23^oC then it is within comfort zone given that the relative humidity lies between 30 and 70%. The air velocity should be within the range of 0.15 to 0.25m/s for summer conditions.

4.4.2 Air Velocity Measurement

A Datamarics instrument was used to measure an air velocity at different locations on each floor of the building. Four different locations on each floor were selected for measuring air velocity. There were some locations in the building where no permission was given to measure the air velocity. On the ground floor, air velocity was within range of 0.07m/s to 1.7 m/s as shown in Table 4.1. There were some locations at each section where air velocity was found to be below 0.15m/s, however, the measured air velocities for all other locations of the building were within comfort range of 0.15-0.25m/s. From questionnaire analysis, more than 50% of the surveyed respondents on the second floor indicated that they felt inadequate ventilation all the time and as can be seen from Table 4.1, there were two zones on the second floor namely the political section and sports section where air velocity was measured below the specific standards which defines the range of air velocity within 0.15-0.25m/s during summer. So it can be said that due to insufficient air movement and air distribution, they felt inadequate ventilation. Similarly, on the ground floor, about 70% of the surveyed respondents indicated that they felt job stress due to thermal discomfort. From air velocity measurement, there were three zones on the ground floor where air velocity was measured below 0.08m/s which is 50% less than the specified range so it can be said that due to insufficient supply air in these zones , they felt job stress.

Table 4.1: Building Indoor Air Velocity Measurement

Floor Name	Zone Name	Air Velocity Logger Location			
		Location # 1 m/s	Location # 2 m/s	Location # 3 m/s	Location # 4 m/s
Ground	Developing Sect.	0.15	0.1	0.13	0.08
	Ladies Sect.	xx	xx	xx	xx
	Advertising Sect.	0.2	0.1	0.06	0.1
	Canteen & Training Sect.	0.07	0.08	0.13	0.17
First	Computer Sect.	0.18	0.15	0.08	0.1
	Mosque	xx	xx	0.08	0.05
	Publication Sect	0.18	0.1	0.2	0.06
	Editing Sect.	0.15	0.1	0.08	0.11
Second	Political Sect.	0.15	0.08	0.18	0.06
	Assistant editor Sect.	0.1	0.07	0.17	0.05
	Local News Sect.	0.15	0.1	0.18	0.22
	Sports Sect.	0.04	0.1	0.19	0.07
Fourth	Assistant Managing Director	xx	xx	0.15	0.1
	Accounting Sect. & Meeting room	0.1	0.15	0.09	0.17
	Administration	0.1	0.15	0.17	0.08
	Maintenance Sect.	0.08	0.1	0.19	0.15
Fifth	Managing Director	0.09	0.15	xx	xx
	Meeting Room	xx	xx	xx	xx
	Chief Editor	0.15	0.1	0.09	0.15
	Office	xx	xx	xx	xx

xx means that air velocity is not measured in these locations

4.4.3 Air Temperature Measurement

Air temperature measurements for three successive days for the months of June, July, August, November and December of 2004 were selected to analyze the data for air temperature. From field survey analysis, majority of zones of the building were found to be within the comfort range of the indoor air temperature for all summer and winter days as shown in Appendix A. As compared with questionnaire analysis, majority of the surveyed respondents were satisfied with the indoor air temperature. However, there were few zones where indoor air temperature was found to be out the comfort rage and is discussed here.

The air temperature for the month of July for the Political Section, director's office, accounting section, administration section and maintenance section zones was mainly out of the comfort range and most of the time, the air temperature was recorded above 26^{o}C as shown in Figures 4.1 to 4.5.

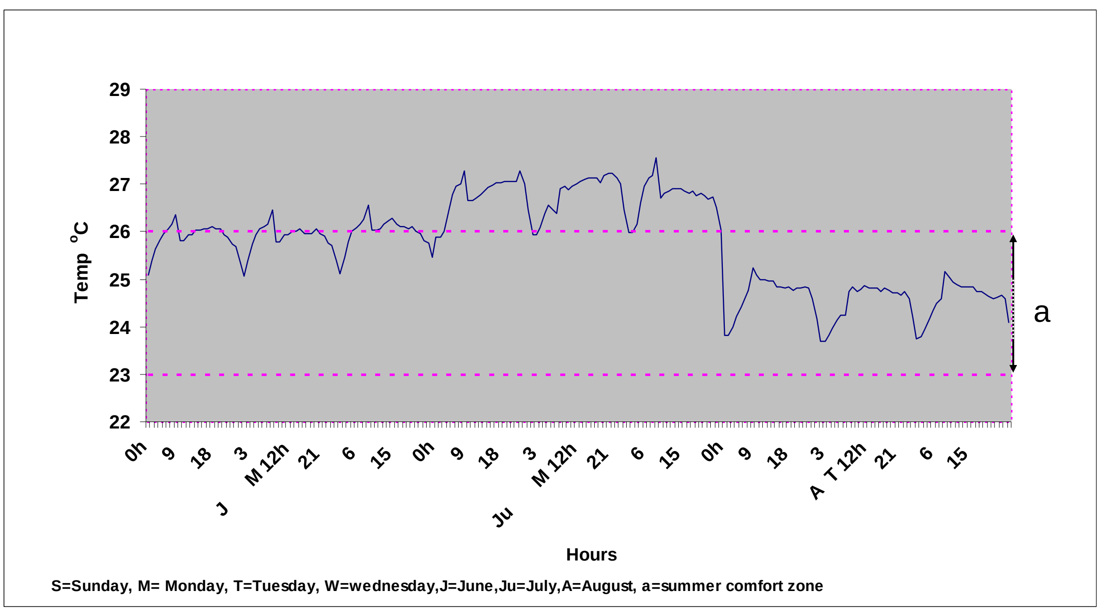

Figure 4.1: Summer days temperature profile for political section

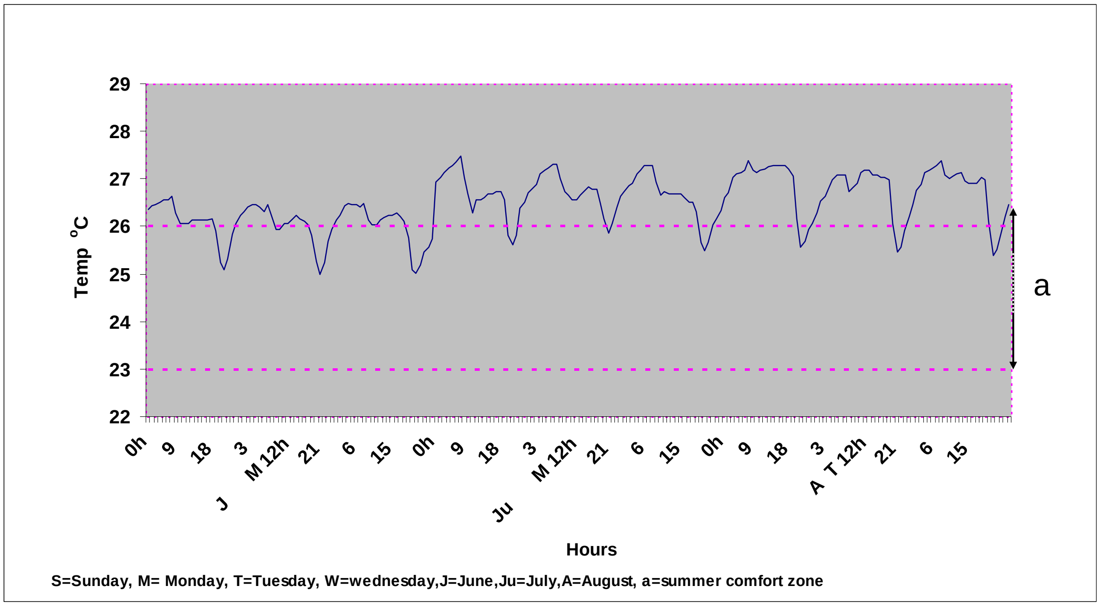

Figure 4.2: Summer days temperature profile for maintenance section

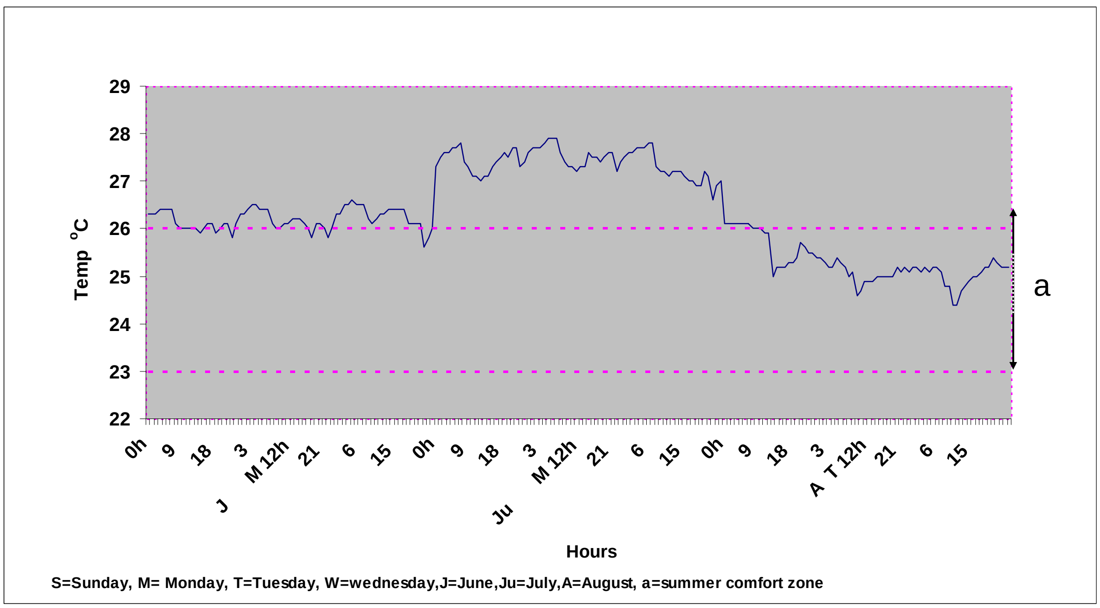

Figure 4.3: Summer days temperature profile for accounting section

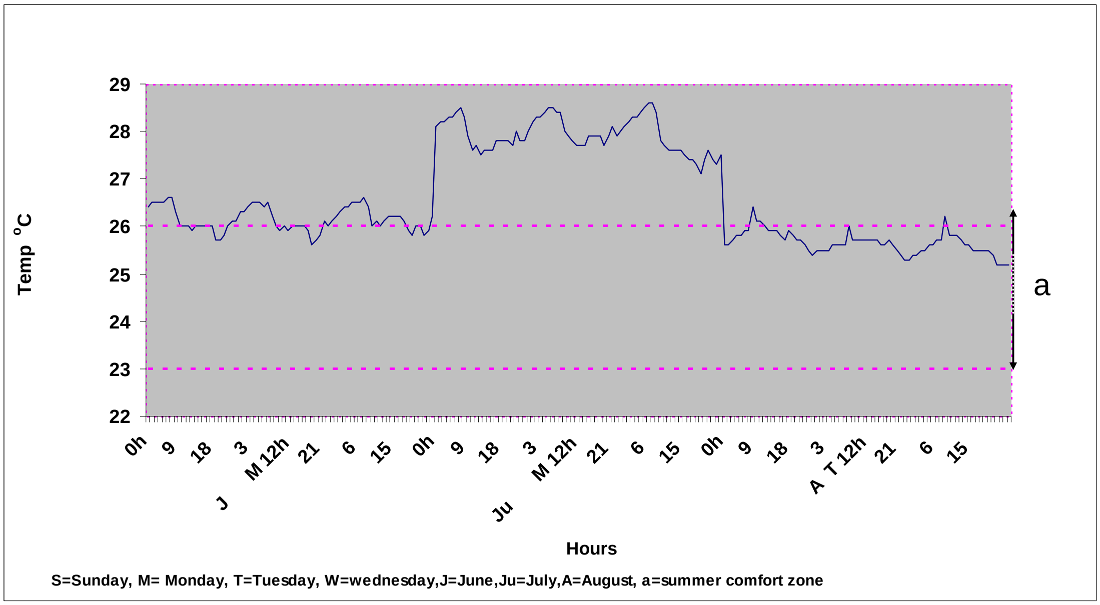

Figure 4.4: Summer days temperature profile for director's office

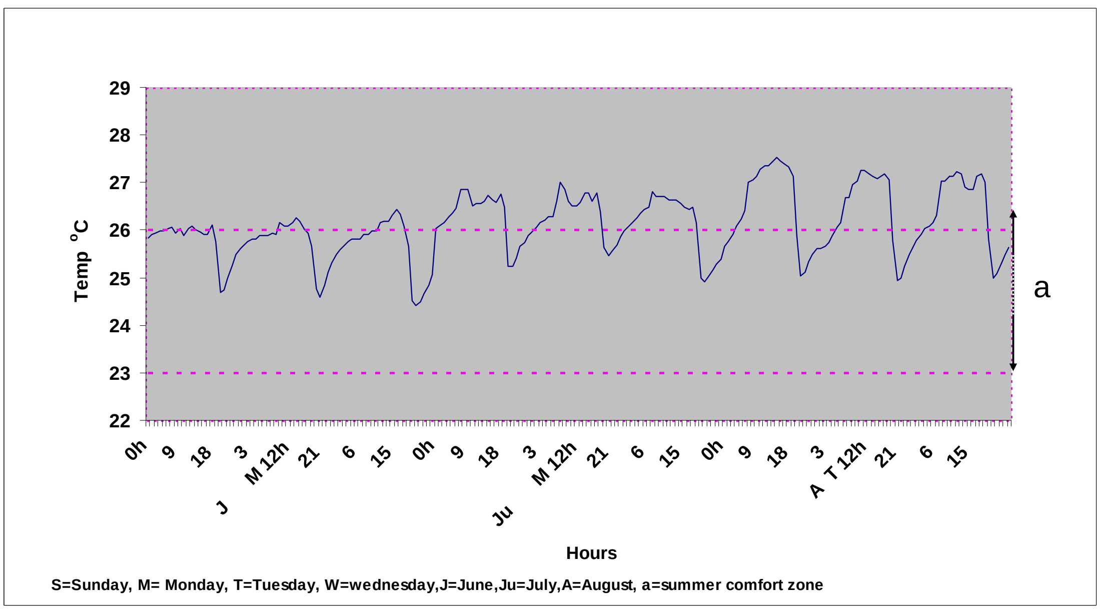

Figure 4.5: Summer days temperature profile for administration section

The questionnaire survey was conducted during the month of August and majority of the surveyed respondents in Political Section, director's office, accounting section, administration section and maintenance section zones indicated their satisfaction with indoor air temperature. From weather data for the year 2004, outside air temperature was recorded up to 48^{o}C in July month as compared to other summer months. For the month of June, it is clear that for the director’s office and the accounting section, the indoor air temperature was out of the comfort range for most hours during all three consecutive days. The indoor air temperature was recorded between 25^{o}C and 27^{o}C. The reason could be the high outside temperature and these zones are located almost top of the building and more heat can enter from windows which can put great impact on inside cooling and inside air temperature, therefore, the indoor air temperature was recorded out of the comfort zone. For the administration section, there were few hours daily when the indoor air temperature was just above 26^{o}C. For the maintenance section zone, recorded air temperature was between 25^{o}C and 27^{o}C which is out of comfort range. The reasons could be the same as mentioned above because these floors are also located on the fourth floor which is almost top of the building. The maintenance people set the indoor air temperature on daily basis and due to high outside air temperature during summer months, it can impact on the indoor air temperature. From questionnaire analysis, the surveyed respondents were satisfied with the indoor air temperature.

On the fifth floor, there are some zones where indoor air temperature was out of the comfort zone. For the month of June, two zones namely, the meeting room and the office section were not occupied for most of the time so the air temperature was above 26^{o}C but below 27^{o}C which was just out of comfort range as shown in figures 4.7 to 4.8 . The indoor air temperature for the month of July for the meeting room and the office section was completely out of the comfort range because there was no occupancy and occasionally these areas were open for special meetings or gatherings. The recorded indoor air temperature for the managing director’s office showed that it was also mostly out of the comfort range and maximum temperature of 28^{o}C was recorded on all three days as shown in Figure 4.6. Again, as discussed above, the questionnaire survey was conducted during August month and from these profiles, the problem exists during month of June and July. These zones are located on the top of the building and during summer months such as the zones of the fourth floor, these zones become hotter due to entrance of direct solar radiation through windows. Also, the outside temperature was as high as 48^{o}C during the month of July, so it has great impact on inside air temperature.

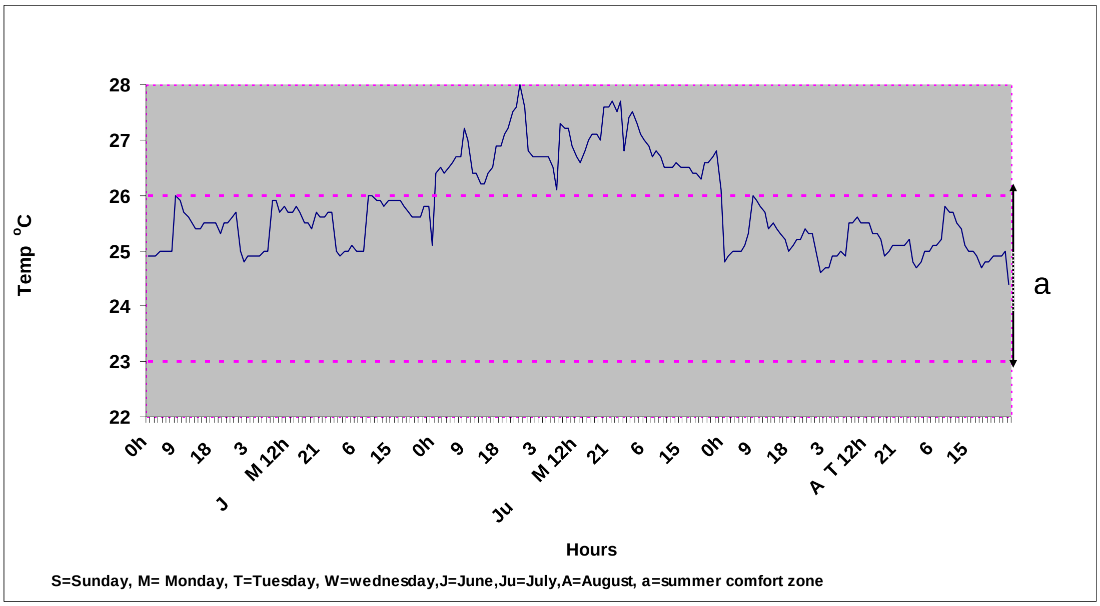

Figure 4.6: Summer days temperature profile for managing director's office

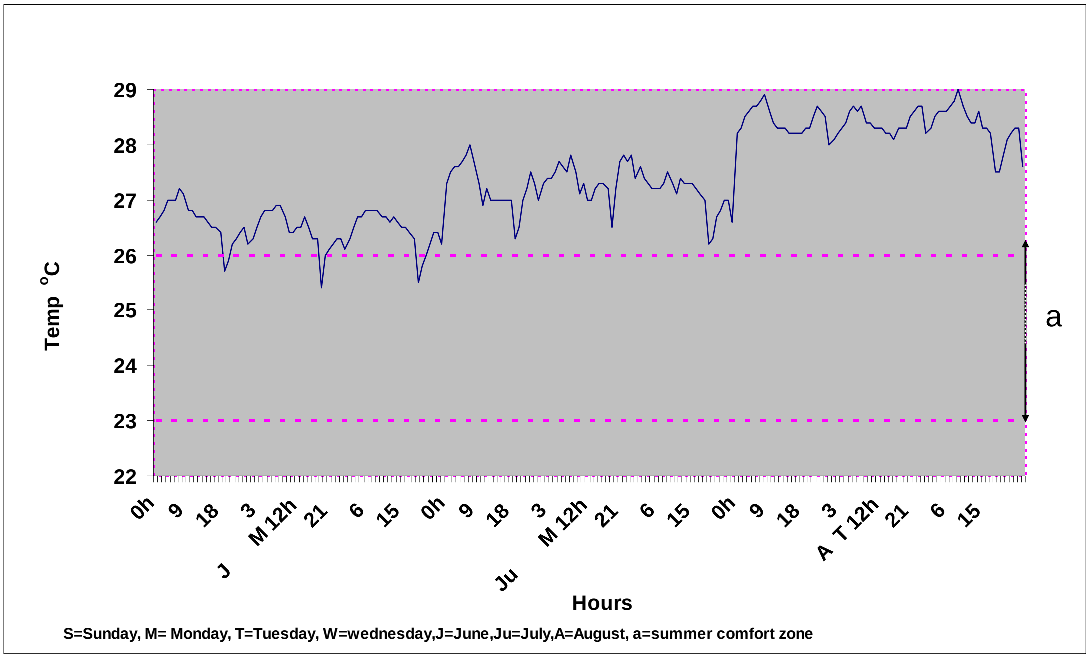

Figure 4.7: Summer days temperature profile for office section

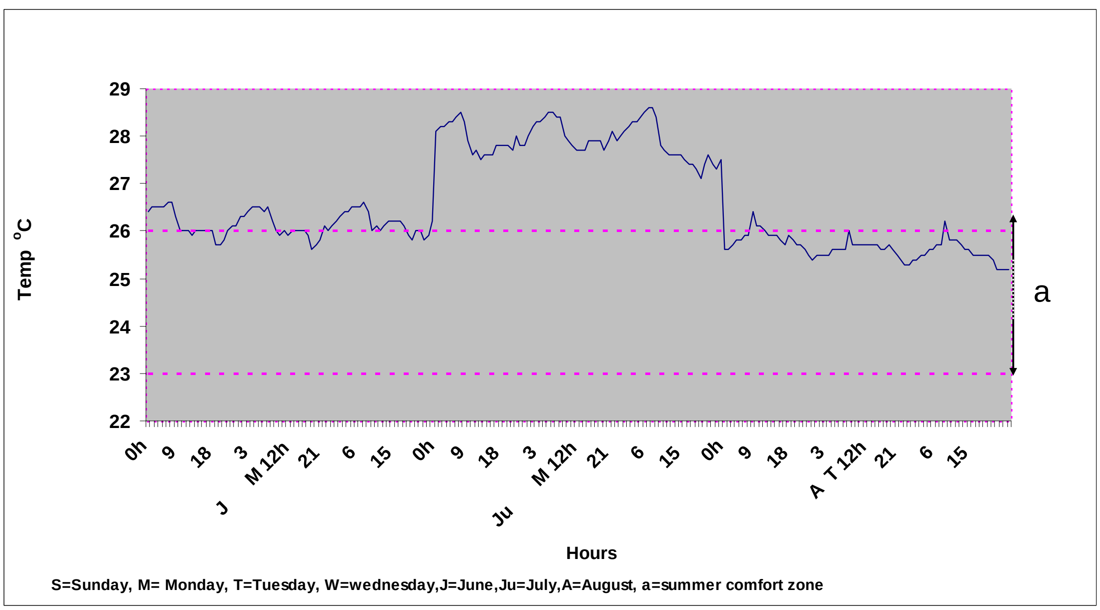

Figure 4.8: Summer days temperature profile for meeting room section

For the winter days, majority of the zones were found to be within comfort zone as shown in Appendix A. However, there were few zones where indoor air temperature was out of comfort range. For the zone design & publication section on the first floor, the indoor air temperature was recorded just below 23°C between 4am to 8am on all three days as shown in Figure 4.9. The reason could be that there were no occupancy during night hours and air conditioning systems might be turned off during night hours. For the local news section on the second floor, the indoor air temperature was recorded slightly out of comfort range between 4am to 6am on Mondays and from 4am to 8am on Tuesdays as shown in Figure 4.10. Again, the measured temperature was out of the comfort zone during night hours and there was no occupancy during that period of time.

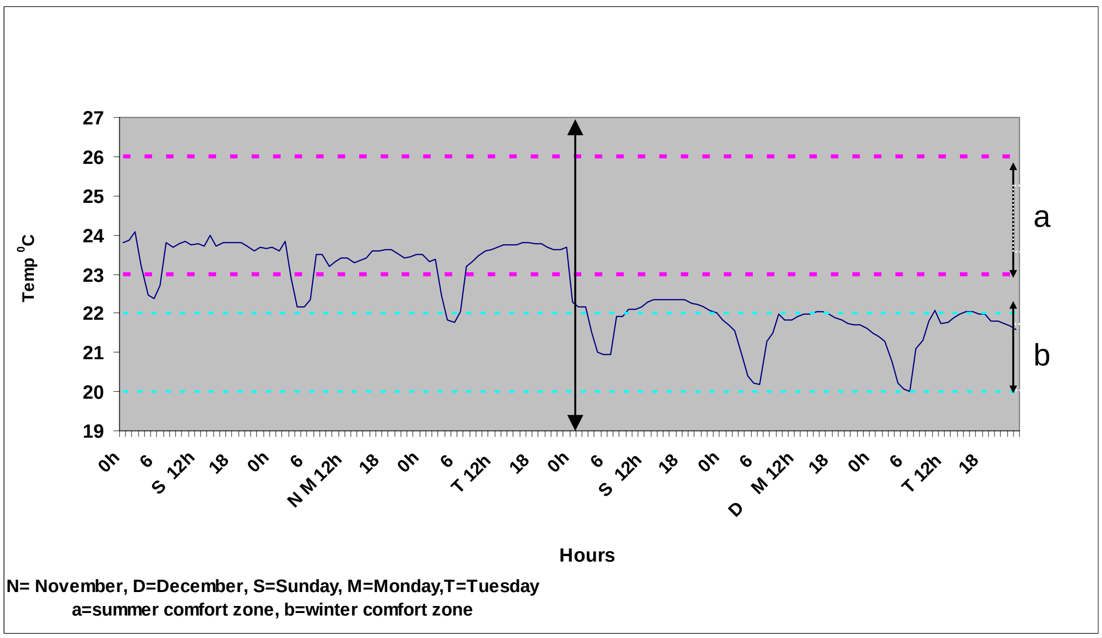

Figure 4.9: Winter days temperature profile for design & publication section

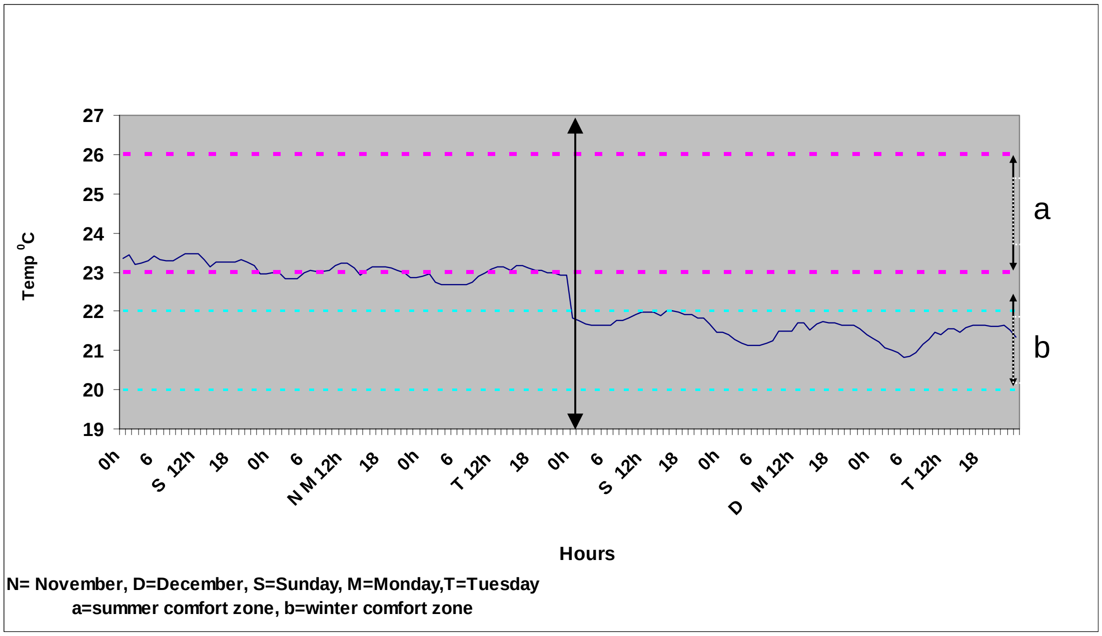

Figure 4.10: Winter days temperature profile for local news section

4.4.4 Air Humidity Measurement

Air humidity measurements for three successive days for the months of June, July, August, November and December of 2004 were selected to analyze the data for air humidity. From field survey analysis, majority of the zones of the building were found to be within the comfort range of air humidity for all summer and winter days as shown in Appendix A. From questionnaire analysis, majority of the surveyed respondents were satisfied with air humidity. However, there were few zones where indoor air humidity was found to be out the comfort zone and is discussed here.

For the advertisement section on the ground floor, air humidity was recorded out of the comfort zone during the month of July between 1am to 8am for Sundays, Mondays and Tuesdays as shown in Figure 4.11. There was no occupancy during night hours; and the air conditioning systems might be turned off during night hours, therefore the indoor air humidity was recorded out of the comfort zone and it doesn’t affect on the occupant’s work performance and their comfort conditions.

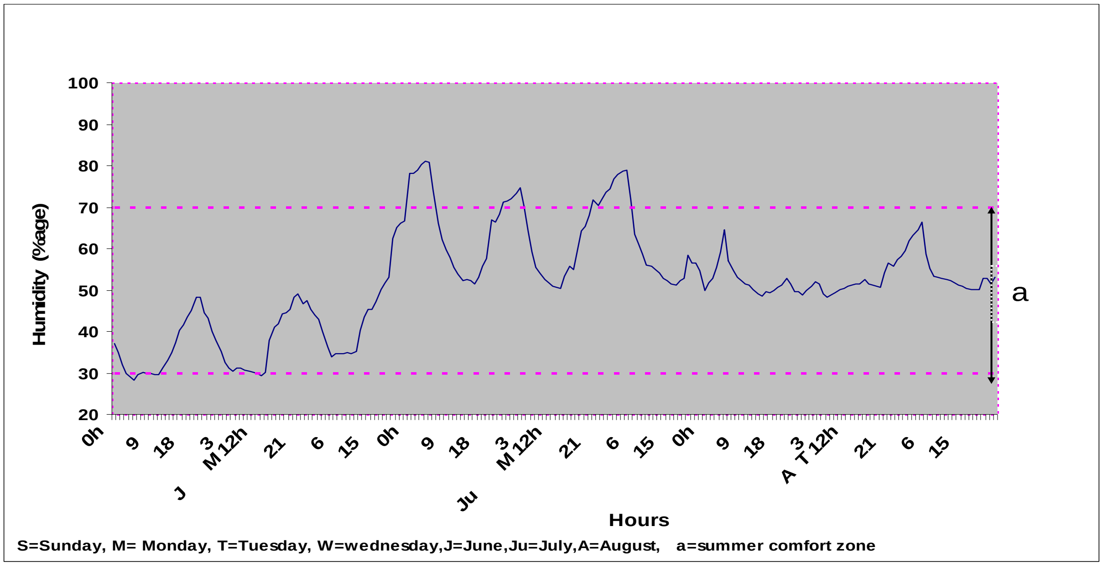

Figure 4.11: Summer days humidity profile for advertisement section

For the month of July, for the design & publication section on the first floor, the air humidity was recorded out of the comfort range for Sundays, Mondays and Tuesdays between 0:00 hours to 0800am as shown in Figure 4.12. For the second floor, the air humidity for all four zones was recorded out of the comfort range between 0:00 hours to 10am for all fours zones on Sundays, Mondays and Tuesdays as shown in Figures 4.13 to 4.16. As discussed above, the questionnaire survey was conducted during the month of august and majority of the surveyed respondesnts were satisfied with the air humidity at their workplaces. During these timings, there was no occupancy and during the month of July, air humidity was high as compared to other summer month, therefore, there is impact of outdoor air humidity on the indoor conditions and due to these reasons, there is variation in air humidity profiles for summer days.

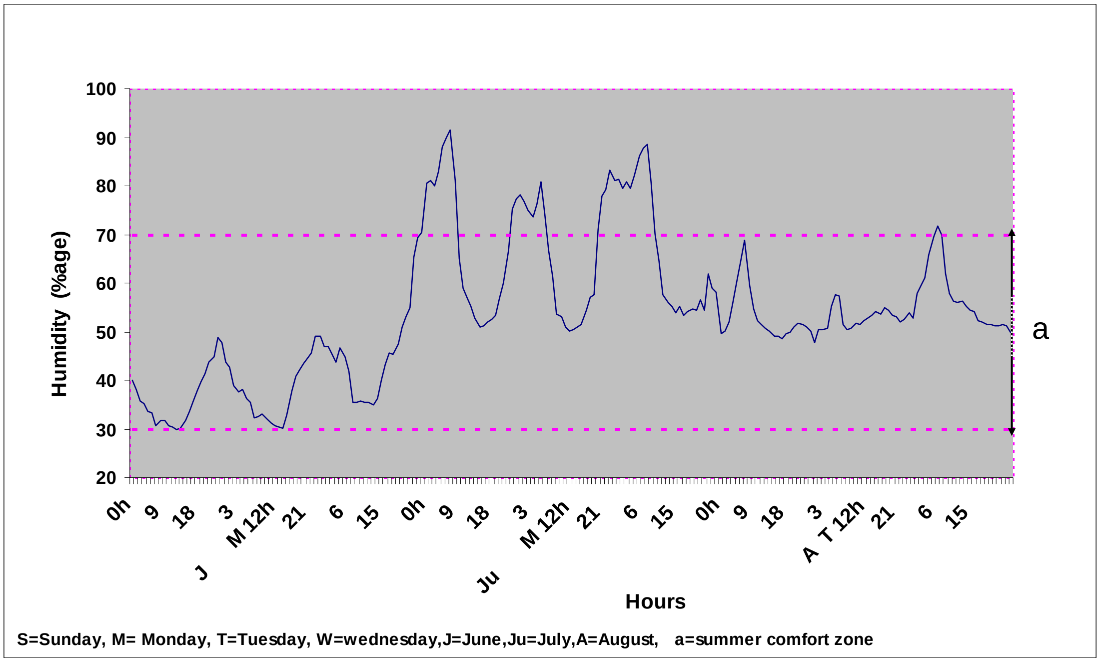

Figure 4.12: Summer days humidity profile for design and publication section

For the month of July, the recorded air humidity for all four zones on the fourth floor namely, the administration section, the maintenance section, assistant managing director's office and accounting section was out of comfort range between 0:00 hours to 9am on Sundays, Mondays and Tuesdays. The air humidity profile for the administration section has been taken as a sample as shown in Figure 4.17. From the figure, it is clear that during night hours, the air humidity was recorded beyond the comfort zone and again the reason is that there is no occupancy during night hours. There was more outdoor air humidity during the month of July and during night hours it increased considerably therefore, it was recorded out of the comfort zone. The questionnaire survey was conducted during the month of August and majority of the respondents were satisfied with the air humidity.

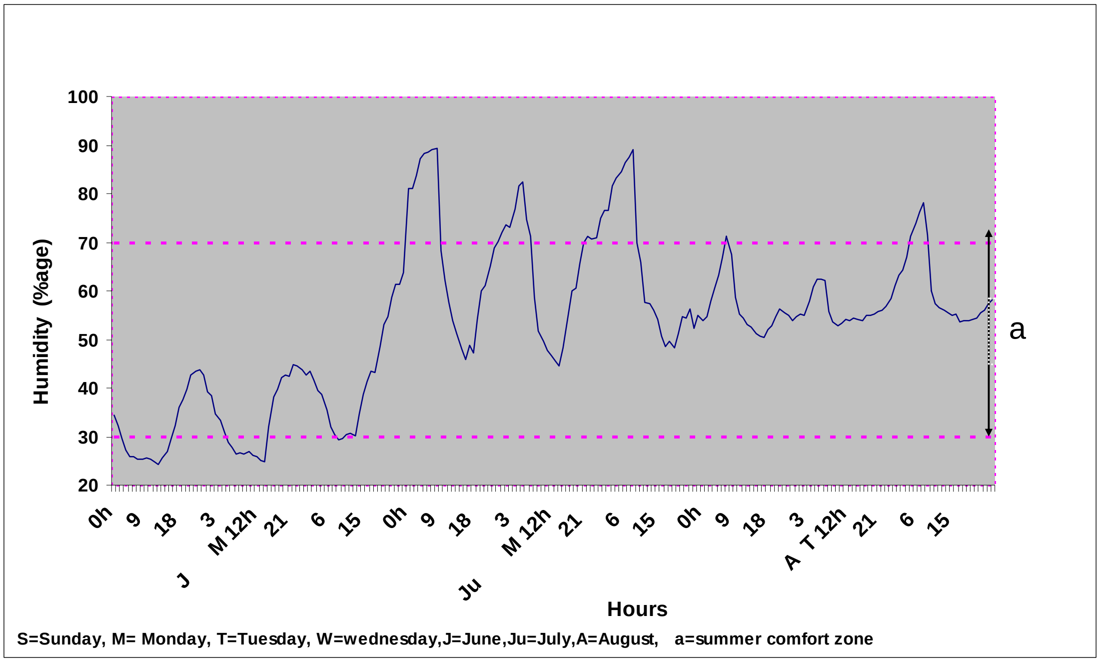

Figure 4.13: Summer days humidity profile for sports section

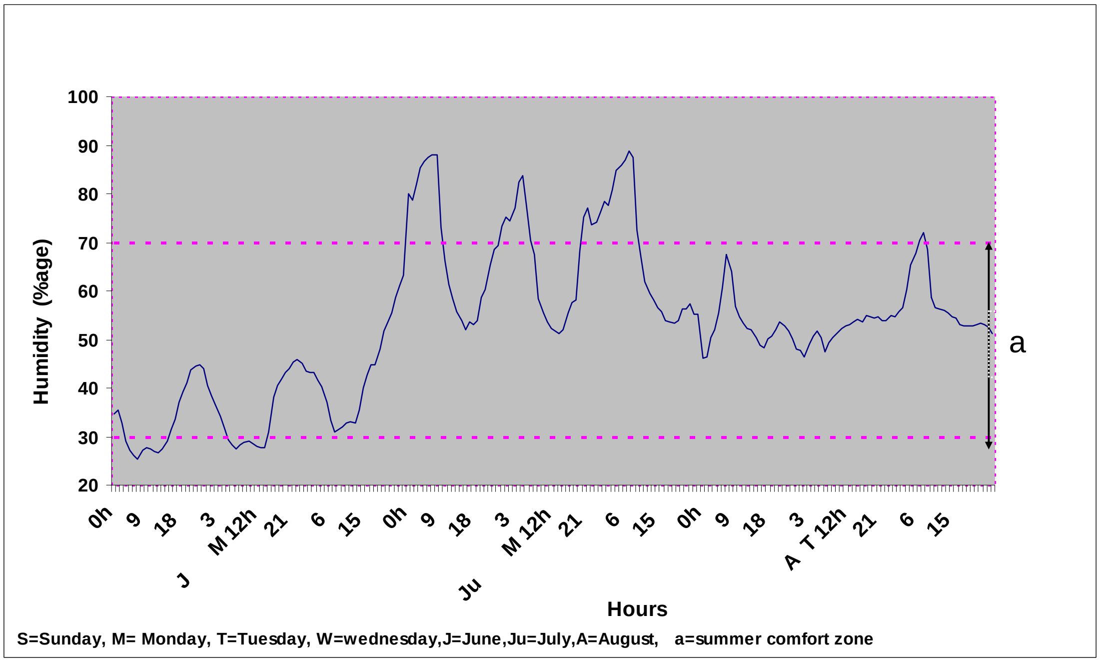

Figure 4.14: Summer days humidity profile for local news section

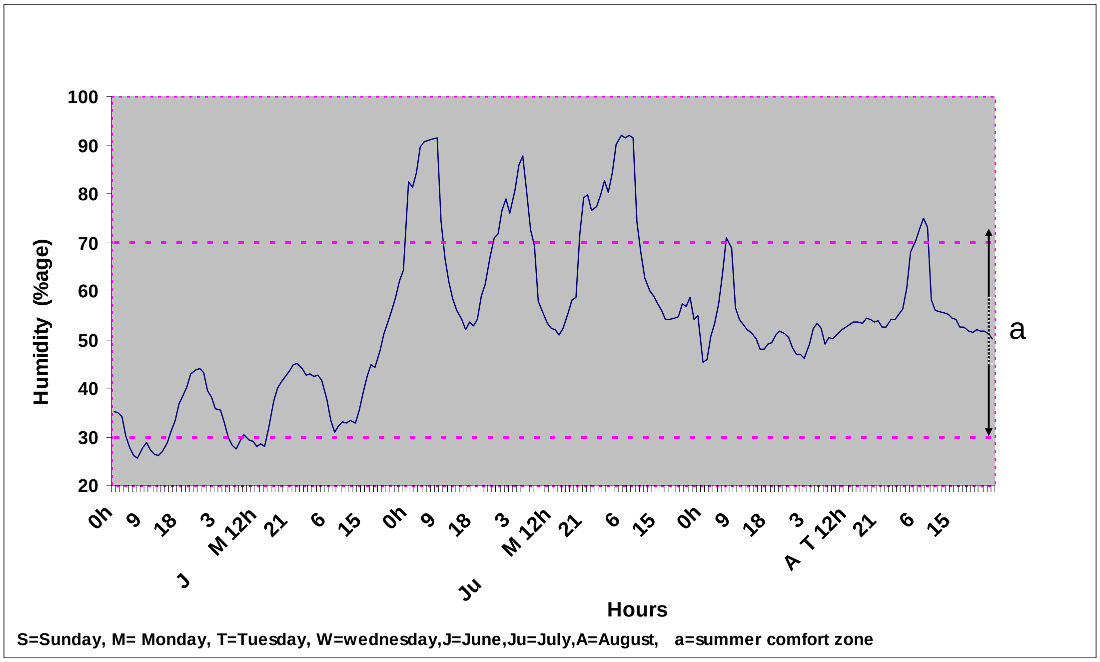

Figure 4.15: Summer days humidity profile for political section

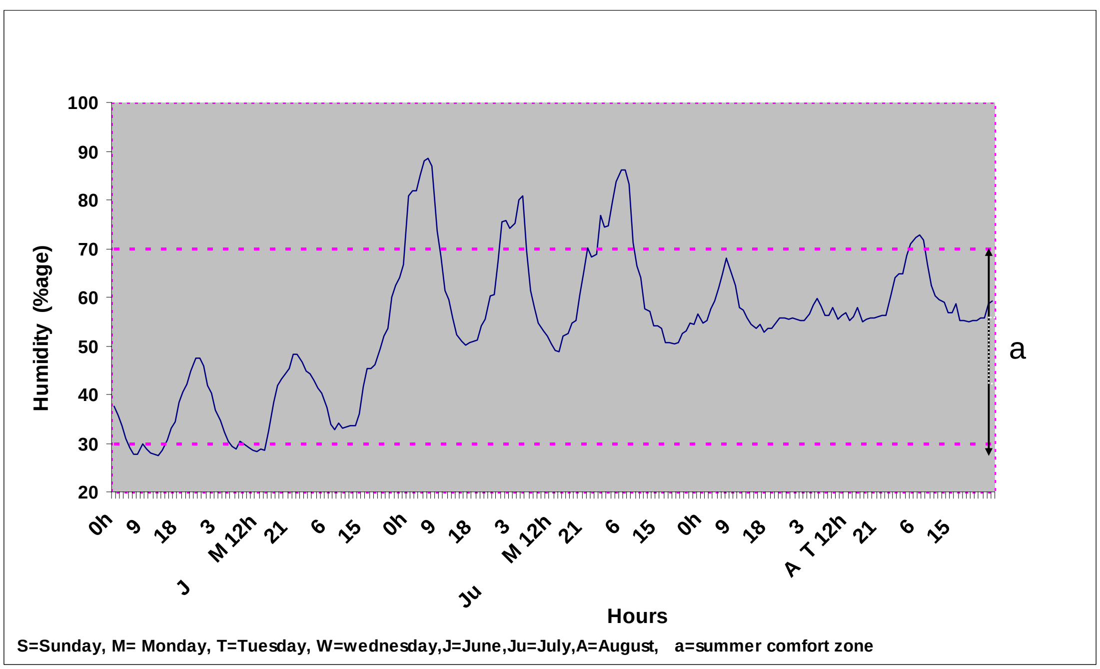

Figure 4.16: Summer days humidity profile for assistant editor's office

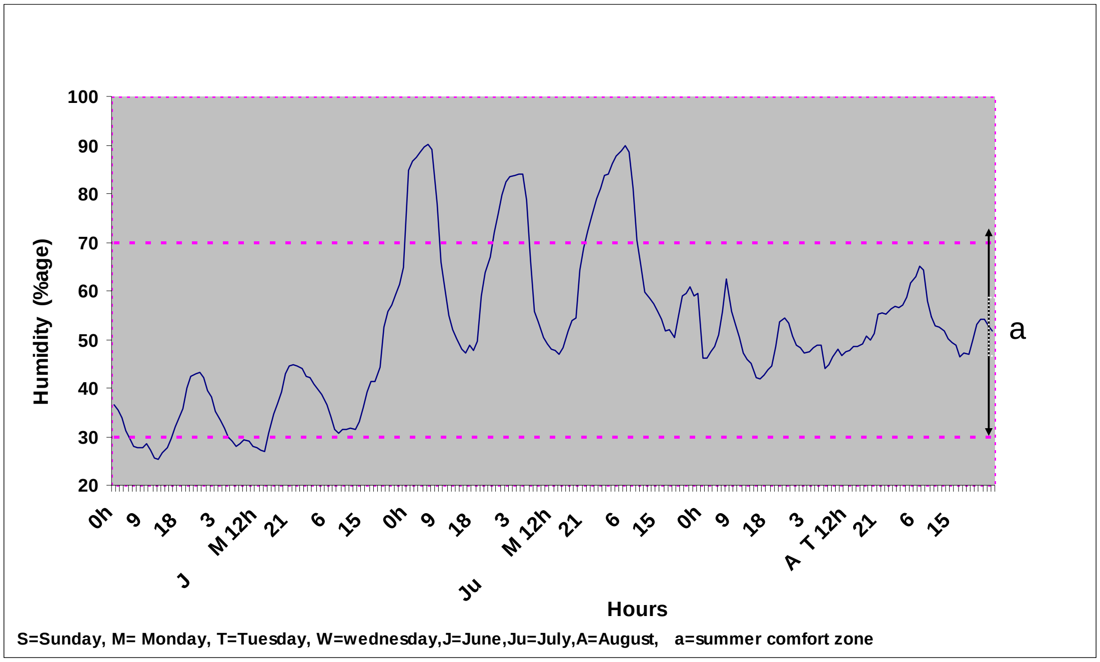

Figure 4.17: Summer days humidity profile for administration section

On the fifth floor for the month of July, the air humidity for all four zones was recorded out of comfort range between 0:00 hours to 9am on Sundays, Mondays and Tuesdays. The air humidity profile for the chief editor's office has been taken as a sample as shown in Figure 4.18. As explained above, this floor is at the top of the building and during summer days such as the month of July, more outside air humidity was found as compared to other summer months from weather data of the year 2004. The questionnaire survey was conducted during the month of August and majority of the respondents indicated their satisfaction with indoor air humidity. During night hours, there was no occupancy and the air conditioning systems might be turned off, therefore, the recorded indoor air humidity was out of the comfort zone during night hours.

For all zones of the building, the air humidity for the winter days was recorded within the comfort range i.e. 30% and 70%. The results are shown graphically in Appendix A.

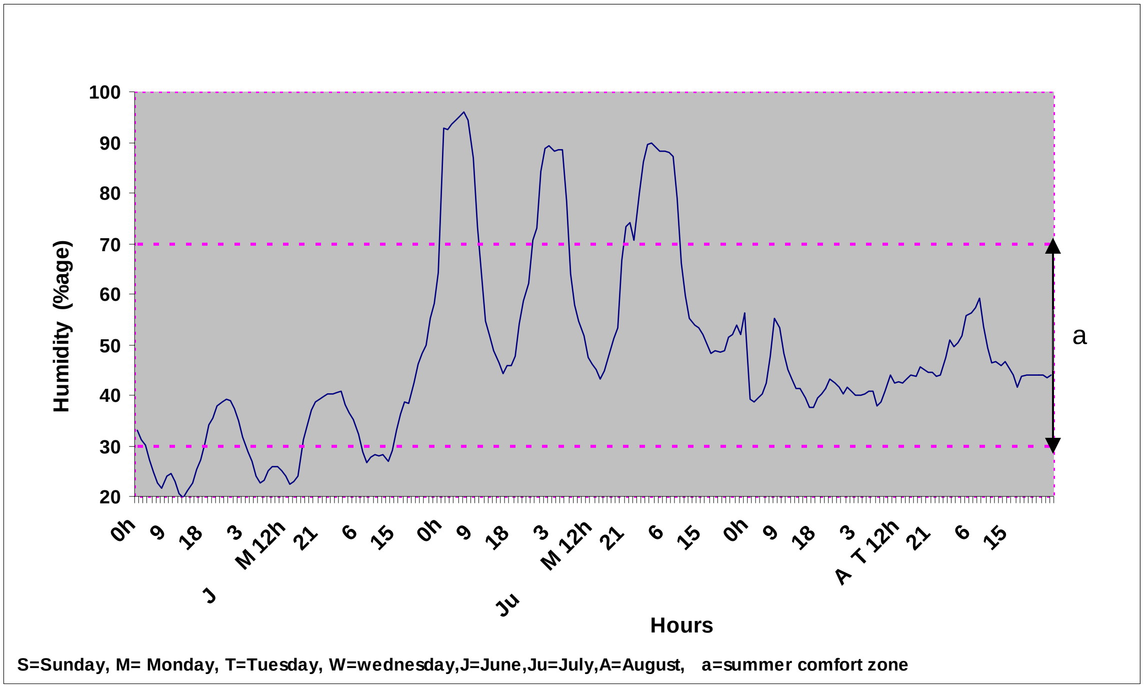

Figure 4.18: Summer days humidity profile for chief editor's office

Conclusively, during summer and winter days, indoor air temperature and humidity were found to be out of comfort zone during night hours especially during the month of July. During night hours, there was usually no occupancy. Also, there were some zones on the fourth and fifth floors where both the indoor air temperature and humidity were found to be out of the comfort zone most of the time during working hours for the month of July. According to weather data for the year 2004, there were variations in indoor air temperature and humidity for all summer days. Therefore, there are fluctuations in recorded indoor air temperature and humidity profiles. Compared with questionnaire survey that was conducted during the month of August, the majority of surveyed occupants indicated their satisfaction with air temperature and humidity and from field measurement analysis, indoor air temperature and humidity were within the comfort zone during August month. There is a need for regular monitoring of thermostat settings so that if there is any temperature change in settings, it should be rectified accordingly.

CHAPTER 5

Building Energy Simulation

5.1 Introduction

Simulation of HVAC energy consumption in buildings is of considerable interest and benefit to engineers and architects. Energy simulation programs can be used to analyze cost effective energy conservation measures before the building is built or modified.

Over the years, large and complex energy simulation computer programs have evolved. These programs are mainly of two types: open source code and proprietary programs. It is intended in this review to focus on the open source type program, to give a broad idea of the main components of these programs, to identify some of the problems encountered by new users and to comment on new trends.

There are two basic levels of energy analysis tools. Simplified energy calculations and detailed energy calculations. Simplified energy calculations are represented by the degree-day method suitable for energy consumption estimates relating to small buildings and the modified-bin-method, which can be used with better accuracy for estimating the energy consumption of larger buildings. Detailed energy calculations apply hour by hour energy simulation. Such programs are used to simulate the energy consumption in a building and its sub systems for every hour of an average weather year [16]. They offer detailed analysis of a building's energy use accounting for all factors such as building schedule, occupancy as well as building mass. They also offer life-cycle cost analysis with different output options depending on the individual program.

The Al-Youm office building was selected as a case study for this research and data about the building occupants, equipment, lighting, HVAC systems and their components was collected for energy simulation.

5.2 Visual DOE 4.0 Simulation Program

History

What is Visual DOE 4.0

Visual DOE is developed by architects, engineers and computer programmers. It was first released in 1994 and has evolved over the years. Visual DOE emphasizes the balance between the ease-of-use and the flexibility for users with different levels of simulation skills and background. In a nut shell, Visual DOE has four major components, the windows user interface, the building and HVAC database, the DOE-2 simulation engine, and the simulation diagnostic and support tools [38]. The user interface facilitates user inputs, output processing, and report generation. The database contains schedules of architectural and mechanical elements, templates of HVAC system and central plant equipment. Visual DOE 4.0 is built on the success of version 3.1 with significant new features and enhancements.

Visual DOE 4.0 is a fourth generation Windows application that enables architects, engineers, energy analysts and utility personnel to quickly evaluate the energy savings of building design options. The program uses the DOE-2.1E hourly simulation tool as the calculation engine so that energy use and peak demand are accurately evaluated on an hourly basis. In the past, energy simulation programs such as DOE-2 have been limited to a small circle of energy experts with special expertise. Visual DOE extends this power to mainstream architects, engineers and energy consultants. Visual DOE is designed so that more advanced calculation engines such as Energy Plus can be used with the interface. The Visual DOE 4.0 Windows interface is truly graphic.

The Visual DOE library can be modified to include special holidays, schedules, equipment templates and other information unique to a particular country or region of the world. Data entry can be speeded through the use of templates. Templates contain schedules of constructions, operation schedules, materials, and other basic information needed to start the project. HVAC equipment templates can also be created and edited with the Equipment Editor Program module. In many cases an entire piece of equipment such as a chiller, boiler or cooling tower can be specified by making a single choice in the templates list box.

Version 1.0 (1994)

Eley Associates released the first graphical interface to DOE-2. Version 1.0 allows quick development of rectangular or L-shaped building models and includes system schematics with point-and-click data entry [38]. Simulation results are extracted automatically from the DOE-2 output files and presented in summary reports.

Version 2.0 (January 1996)

Complex building shapes can be created by dragging and dropping a library of shapes on up to ten plan levels. Each plan shape (or block) can have one of several standard zoning patterns, or a block can be divided into custom zones. DOE-2 input files are easier to understand since they do not use macros. Diagnostic features are improved [38].

Version 2.5 (November 1996)

Significant updates from version 2.0 with many new features such as added custom block editor with CAD file import, hourly reports editor, graphing of output, time-dependent plant load-management, thermal energy storage, multiple blocks on the same level capability, zone open-to-below capability, window sill height entry, weather file statistics, graphing of custom equipment curves, and new architectural summary report.

Version 2.6 (December 1997)

More updates and assorted improvements including custom performance curves for fans, cooling coils and heat pumps have been done.

Version 3.0 (December 2000)

Moderate updates to the look of the interface and major updates to the software structure to allow for greater flexibility in future updates [38]. Overhaul of software structure from 16-bit code to 32-bit using object oriented technology. New features included new custom block editor, new custom façade and skylight editor, new 3D viewer, and new utility rate editor, updated schedule and construction editors, create up to 99 alternatives, download updates via the internet.

Version 3.1 (December 2002)

Significant updates from version 3.0 with many new features, improvements and bugs fix. New features include LEED style end-use report, weather file converter, allow a big model with 1024 zones and 256 systems, shows building statistics while you build an energy model, some new 3D view controls, share library file to make Visual DOE network compatible, define source energy use and process loads of a room, add escalation rate at the utility rate editor for life cycle cost calculation, adds emissivity to the outside surface of a construction under construction editor.

5.3 Input Data Collection

Each zone of the building was physically visited with the cooperation of the administration for getting information about lighting, equipment and number of people.

5.3.1 .Building Envelope (Wall, Roof and Glazing)

For buildings, the envelope (i.e. walls, roofs and windows) have an important impact on the energy used to condition the facility. So, there is a need to determine the actual characteristics of the building envelope. For this purpose, the building architectural engineering drawings were reviewed for getting details of wall, roof and glazing characteristics. Important information, for instance, type of insulation in walls and roofs, type of window and its characteristics were obtained using building architectural engineering drawings. Details of the wall, roof and glazing are shown in Table 5.3

5.3.2 Internal Loads (People, Equipment, Lighting)

The equipment used in this office building was personal computers, small and large printers, Xerox machines, and few scanners. For calculating equipment and lighting power densities, the following procedure was adopted with the consultation of ASHRAE standard [13]:

For each zone of the floor, total number of equipment and lighting fixtures was counted and using ASHRAE standards, the power densities of equipment and lighting were calculated. Total number of occupants was counted. The total wattage for different equipment is shown in Table 5.1. All tabular data is shown in Table 5.2.

Table 5.1: ASHRAE Standard for Equipments (ASHRAE Hand Book of Fundamentals 2001)

Equipment Name	**Wattage W**
Monitor	70
Printer	400
Copier	1100

Table 5.2: Details of Building lighting, equipment and people

Floor Name	Zone Name	Lighting Power Density (LPD) W/m^2	Equipment Power Density (EPD) W/m^2	Number of people
Ground	Developing Sect.	25	25	15
	Ladies Sect.	10	10	7
	Advertising Sect.	15	35	10
	Canteen & Training Sect.	10	10	25
First	Computer Sect.	20	30	20
	Mosque	5	5	10
	Publication Sect	20	30	25
	Editing Sect.	20	30	15
Second	Political Sect.	20	30	15
	Assistant editor Sect.	20	30	15
	Local News Sect.	20	30	15
	Sports Sect.	20	30	15
Fourth	Assistant Managing Director	20	16	16
	Accounting Sect. & Meeting room	20	20	20
	Administration	20	16	16
	Maintenance Sect.	20	10	10
Fifth	Managing Director	10	10	6
	Meeting Room	10	10	6
	Chief Editor	10	10	5
	Office	10	10	6

5.3.3 HVAC Systems

Information about HVAC systems, air handling units (AHU’s) and chillers was collected with the cooperation of maintenance administration of the building. A constant air volume (CAV) system was used for air conditioning and reciprocation chillers were used. Four chillers and twenty four (24) air handling units (AHU's) were used in the office building in total. All information about chillers, condenser and chiller schedule, timing schedule of AHU's, is presented in Appendix E.

5.3.4 Review of Design Drawings

Architectural drawings were carefully reviewed to get data about construction details of walls and roofs (Appendix B). Also engineering drawings were analyzed to get information about glazing and details about lighting systems. The details are given in Table 5.3.

The HVAC system drawings were examined to check for the total number of air handling units, their power consumption, chiller system and its power consumption. The details about the timing schedule of air handling units (AHU) and their other details, chiller and condenser schedules and pump schedule were given in Appendix E.

Table 5.3: Physical Characteristics of the building

Component	Description
Wall	200mm Concrete block
	50mm Polyutherine Insulation
	Inside & Outside Layers
	U-value = 0.36 W/m^2k
Roof	200mm Concrete block
	50mm Polyutherine Insulation
	Inside & Outside Layers
	U-value = 0.36 W/m^2k
Glazing	Double glazed 6/12/6mm
	Blue Colour
	U-Value = 3.5 W/m^2k
	Shading Coefficient = 0.3
	Transmittence = 0.7
People (Number Of People)	271
Lighting	325 W/m^2
Equipment	455 W/m^2
Type of lighting	Flourecent
Ventilation Rate	7.5 L/S/Person
Infiltration rate	0.2ach
HVAC system	Constant Volume System
	Total AHU'S = 24
	Each AHU Power Rating= 7600 Watts
	Number of Zones = 24
Chillers	Type = Reciprocating
	Capacity = 736 KW
	Number of Chillers = 4
	Water Supply temperature = 7^oC
	Water Return temperature = 13^oC
Set point temperature	22^oC-25^oC (Summer)
	20^oC-22^oC (Winter)

5.3.5 Utility Bills Data

From utility bills data, valuable information can be obtained about building energy use which can be compared with target values or compared with similar buildings. For most buildings, utility bills give information about total building consumption including lighting, heating, cooling, equipment and appliances. In order to identify major energy consuming areas, either separate monitoring is carried out or monitoring of selected components plus utility bills can be used to identify energy flows in buildings. The energy use pattern can be obtained from the compilation of utility bills over the last four years. Analysis of utility bills allows the energy auditor to determine if there are any seasonal and weather effects on the building energy use.

For the investigated office building, utility bills for the last four years from January 2001 to December 2004 were collected on request from building officials (Appendix F). This data provided sufficient information about annual energy consumption and also helped in calibrating the energy simulation program. Monthly energy consumption billing data for the four years is presented graphically Figure 5.1.

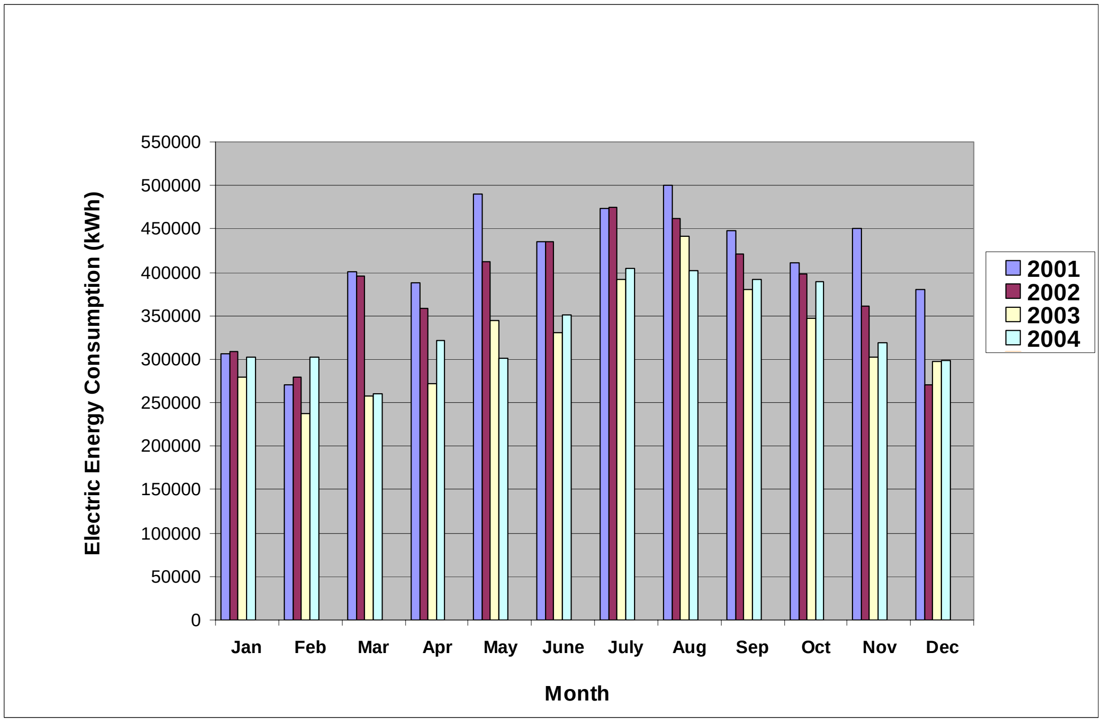

Figure 5.1: Monthly four years energy billing data for Al-Youm office building

As can be seen from Figure 5.1, it is clear that the electric energy use was found to be increased during summer months (June through November) when the outdoor air temperatures are high. During winter months, electric energy use was lower due to lower outside air temperature. More electric energy was found to be consumed for the years 2001 and 2002 during summer months as compared to other two years. For the year 2001, for the months of May, November and December, more electric energy was found to be consumed as compared to other years. The energy use pattern for the month of January was found to be almost the same for the all four years. Conclusively, from the analysis of all four years utility bills data, there is a variation in monthly electric energy use due to any seasonal and weather effects.

The average energy consumption was calculated on a monthly basis and it can be seen from Table 5.4 that the minimum energy consumption was found to be in the winter months from December to March. On an average, the maximum energy consumption was found to be consumed in hot and humid months every year.

Table 5.4: Average Monthly Energy Consumption

Month	Days	Electric Energy kWh
Januray	31	303148
February	28	287591
March	31	321329
April	30	335193
May	31	375885
June	30	387987
July	31	429496
August	31	441000
September	30	410327
October	31	373418
November	30	358390
December	31	309252

Table 5.5 shows the annual energy consumption of the building in kWh/y.m^2. More annual electric energy was found to be consumed in the year 2001 which was 410 kWh/m^2. Minimum electric energy was found to be consumed in the year 2003 which was 315 kWh/m^2.

Table 5.5: Four years annual energy consumption in kWh/m^2

Year	kWh/year.m^2
2001	410
2002	377
2003	315
2004	330

The annual electric energy for the years 2002 and the year 2004 was found to be 377 kWh/m^2 and 330 kWh/m^2 respectively. From utility bills data, there is a variation in annual energy consumption for all four years and the reason for this would be the weather conditions for the specific year. There can be other reasons such as set point temperature and internal loads for the specific year.

A case study was conducted on an office building in Riyadh area during the year 1997 [19]. The annual electric energy use for this case study office building was 300 kWh/m^2. From this analysis, there is little difference because the weather conditions in Riyadh are dry and hot.

5.4 Building Energy Simulation Analysis and Discussion

5.4.1 Introduction

The main purpose of the building energy simulation analysis is to evaluate the characteristics of the energy systems and the pattern of the energy use for the building. It can also be used to study the impact of building modifications on building energy use. Alternative designs or materials can immediately be evaluated to see how much they effect the annual energy consumption. This could lead to select energy efficient designs without sacrificing human comfort. The energy use patterns were obtained from a compilation of utility bills over last four years. Visual DOE 4.0 software is used to develop a base case and for an energy simulation analysis. The building characteristics were collected from architectural, electrical and mechanical drawings.

5.4.2 Base Case

The main purpose of this step was to develop a base case model that represents the existing energy use and operating conditions for the building. The major tasks performed during that step were:

- Obtain and review architectural, mechanical and electrical drawings;
- Obtain all occupancy and operating schedules for equipment (including lighting and HVAC systems);
- Develop a base-case model for building energy use; and
- Calibrate the base-case model using utility bills data.

All the collected data was used in Visual DOE software including the construction of walls and roofs, details of glazing, schedules including people, equipment, lighting, outside air, set point temperatures and the schedule of HVAC systems. Dhahran weather data for the year 2002 were used for modeling.

5.4.3 Simulation Program Calibration

A base case model was developed using all the collected information and base case monthly energy consumption was calibrated based on available utility bills data for the year 2002. Utility bill for the year 2002 were used because DHAHRAN weather data for the year 2002 is used in a simulation program. The available data are based on lunar months and on random daily basis for each month are shown in Appendix F.

For calibration purposes, utility bills for the year 2002 were divided to months such as 28 days for the month of February, 31 days for the months January, March, May, July, August, October and December and 30 days for the months of April, June and September as shown in Table 5.6.

Table 5.6: Monthly utility bills data for the Year 2002

Year	Month	Days	Energy Consumption KWH
2002	Jan	31	309132
	Feb	28	279227
	Mar	31	395908
	Apr	30	358137
	May	31	412620
	June	30	435000
	July	31	475200
	Aug	31	461677
	Sep	30	420827
	Oct	31	398040
	Nov	30	360642
	Dec	31	270000

Initially, monthly energy consumption for base case was as much as 22% difference from utility bills data for the year 2002. Trials were made to manipulate the input data with different behavioral parameters such as set point temperatures, schedules and infiltration rate as shown in Table 5.7 to closely match the base case monthly energy consumption with utility bill data for the year 2002.

Table 5.7: Input data for initial trial and final base case

Component	Intital Trial	Final Base Case
Insulated Wall	75mm Polyutherene Insulation	75mm Polyutherene Insulation
Insulated Roof	75mm Polyutherene Insulation	75mm Polyutherene Insulation
Double Glazed Window (6/12/6mm)	U=3.5 W/m^{2}K	U=3.5 W/m^{2}K
	SC=0.3	SC=0.3
	SHGC=0.26	SHGC=0.26
	Trasmittance=0.7	Trasmittance=0.7
	Colour=blue	Colour=blue
Energy Efficient lamps	40 watts Fluorescent Type	40 watts Fluorescent Type
Set Point Temperature	23^{o}C for Summer and Winter	25^{o}C (summer) and 22^{o}C (winter)
Schedule of Lighting & Equipment	100% Use of Lighting & Equipment	Reduce the usage upto 60% during low occupancy and night hours
Inflitration rate	0.45ach	0.20ach
HVAC system	Constant Air Volume System	Constant Air Volume System
	Air Cooled Reciprocating chillers	Air Cooled Reciprocating Chillers

For calibration purposes, indoor set point temperature for winter and summer months was separately used. Schedules of people, lighting and equipment were adjusted and different infiltration rates were used for office building.

Figure 5.2 shows the final monthly electrical energy consumption for base case model predicted by the DOE 4.0 and the actual energy use recorded in the year 2002 for the building. It shows that DOE 4.0 predicts the energy use pattern of the building fairly well especially in the summer months which includes June, July and August as this study was mainly for hot and humid climates. The comparison of the monthly energy use data and percentage difference between the base-case and the actual building is shown in Figure 5.2.

As can be seen in Figure 5.2, there is less than 5% difference for the months of June and August and 10% difference for month of July between the simulation program and utility bills for the year of 2002. These results are acceptable because there is a difference of 10% or less for all the months between the base case model and utility bills for the year 2002.

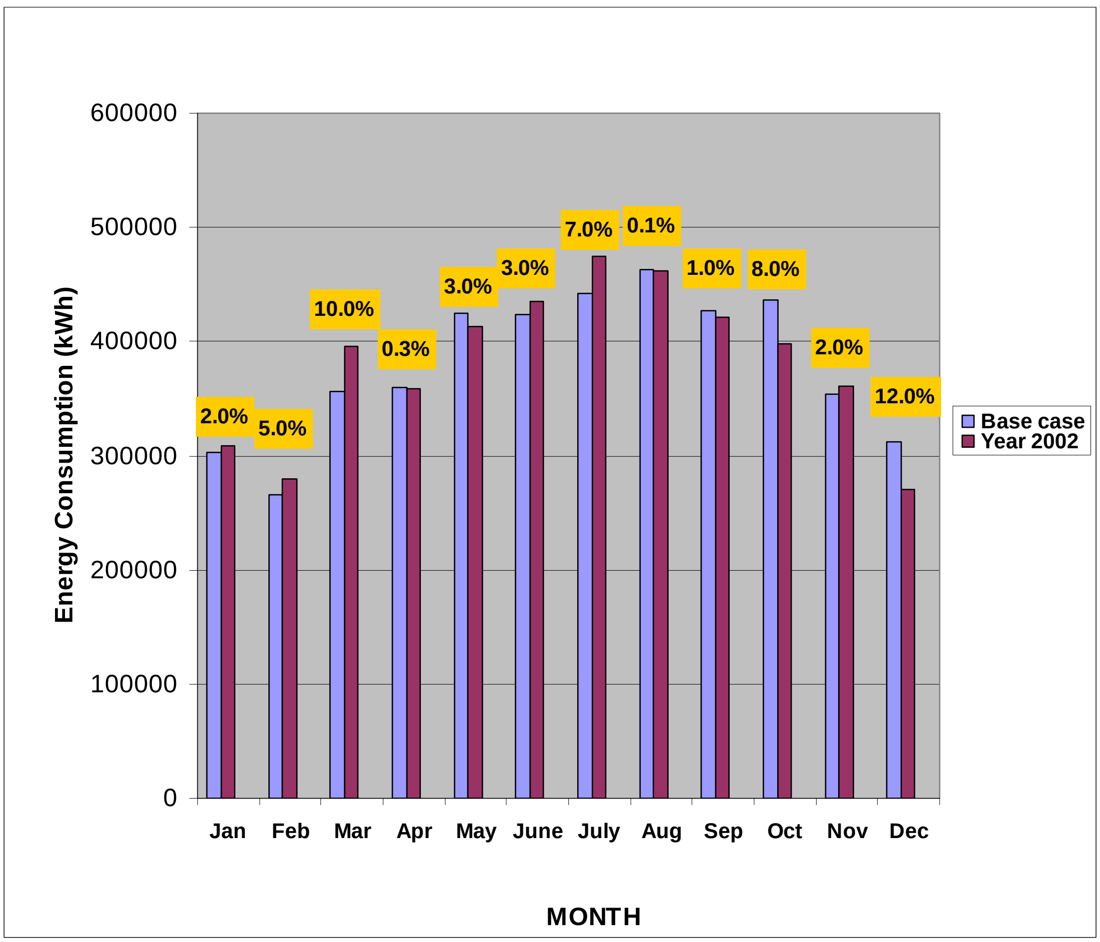

Figure 5.2: Comparison of simulation prediction and actual building electrical use

5.5 Evaluation of Alternative Energy Conservation Measures

Based on the evaluation of energy use pattern of the building, several energy conservation measures (ECM's) for the building were analyzed. Energy conservation measures were classified into three categories as shown in Table 5.8. These categories include:

- No cost measures
- Low cost measures
- Major investment measures

Table 5.8: Details of energy conservation measures

Level of Measures	ECM	DESCRIPTION
No Cost Measures	Set point temperature	26^{o}C (S) and 20^{o}C (W)
	Night time set back	28^{o}C (S) and 16^{o}C (W)
	Schedule of lighting & equipment	Low occupancy period & night times
Low Cost Measures	Insulated wall and roof	50mm polyutherene insulation
	More efficient glazing system	Low emittance double glazed window
	Energy efficient lamps	More efficient luminaires of fluorescent type
Major Investemnt Measures	HVAC system	Replacement of CAV with VAV system
		More efficient reciprocating chillers

Details of the input data for base case and each of the energy conservation measure (ECM) are shown in Appendix G. All the three categories of energy conservation measures were discussed in details below:

No Cost Measures

These are measures that can be implemented through operational means without the need for system or building alterations and, therefore, donot require extra cost for their implementation.

ECM # 1: Set point Temperature

In this ECM, the impact of indoor temperature setting on energy use is analyzed using the DOE 4.0 computerized simulation program. The cooling temperature was set at 26°C for summer and at 20°C for the winter. For the real base case, as an average, the indoor air temperature was set at 24°C for summer and at 20°C for winter. The results are shown graphically in Figure 5.3

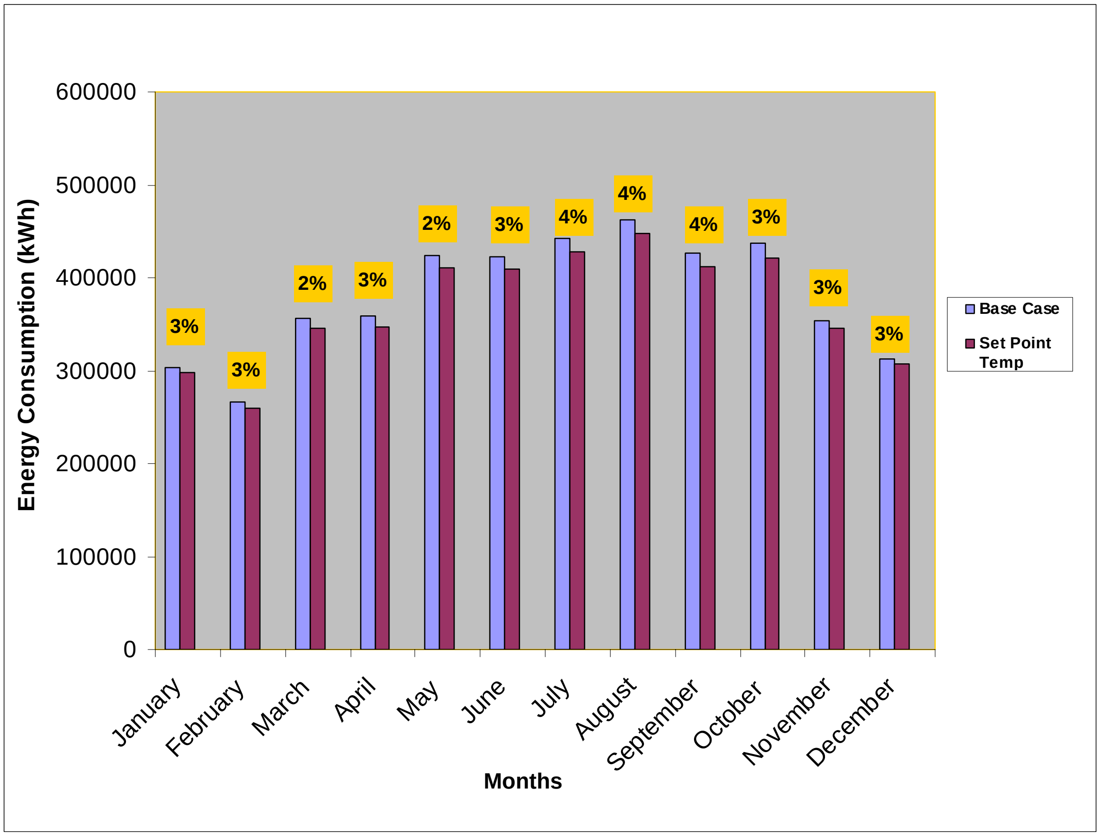

Figure 5.3: Comparison of monthly energy consumption between Set Point Temperature and Base case

In this ECM, on an average, 3% reduction in energy consumption is achieved by adjusting the thermostat setting. This ECM is only operational and does not cost anything.

ECM # 2: Night time setback

In this ECM, an indoor air temperature was adjusted for night time to reduce the energy consumption. Also, this ECM is used for unoccupied periods which are at mid night until 7am the next morning. The indoor air temperature was set at 28°C for summer and at 16°C for winter. The results are shown graphically in the Figure 5.4.

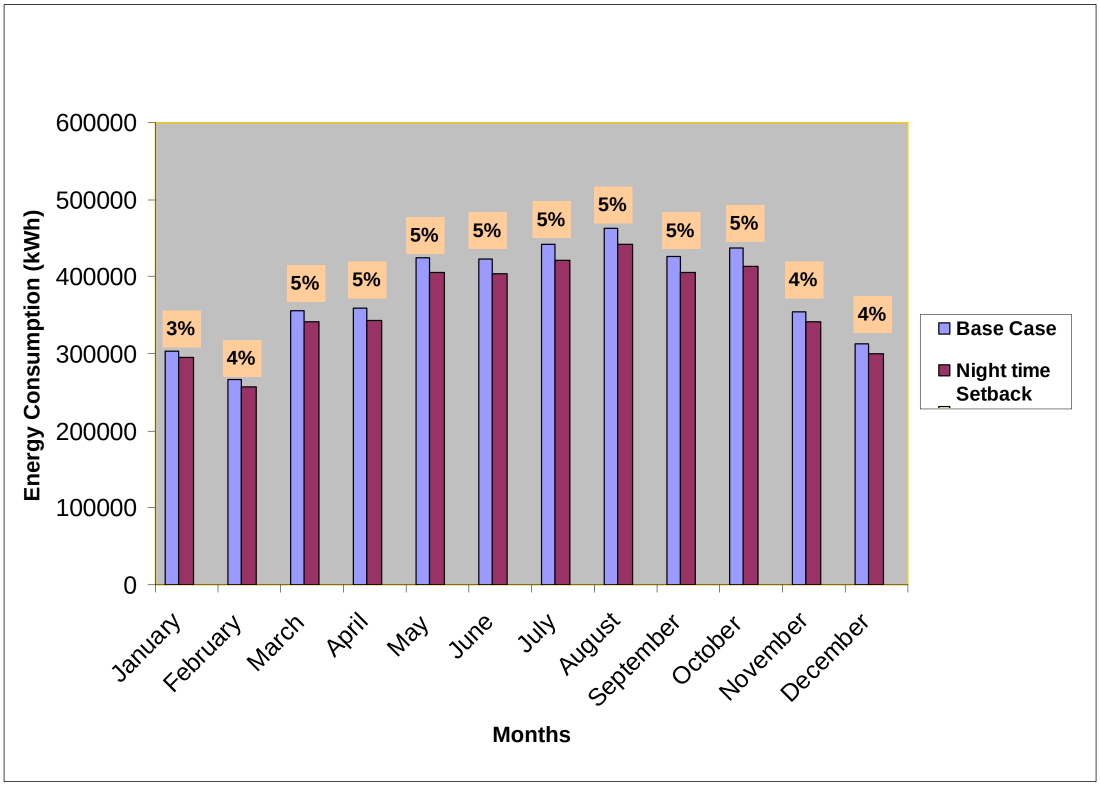

Figure 5.4: Comparison of monthly energy consumption between Night time Setback and Base case

In this ECM, on an average, a 5% reduction in energy consumption especially in summer months is achieved by adjusting the thermostat setting at night time. This ECM is usually applied to unoccupied periods of time.

ECM # 3: Schedule of Lighting & Equipment

This is also an important ECM regarding scheduling of lighting and equipment. For the existing building, lighting and equipment were used all the time during unoccupied and low occupancy hours. In DOE 4.0 simulation program, the schedule of lighting and equipments were adjusted by turning off lighting and equipments during unoccupied and low occupancy hours and the monthly energy saving is shown graphically in Figure 5.5.

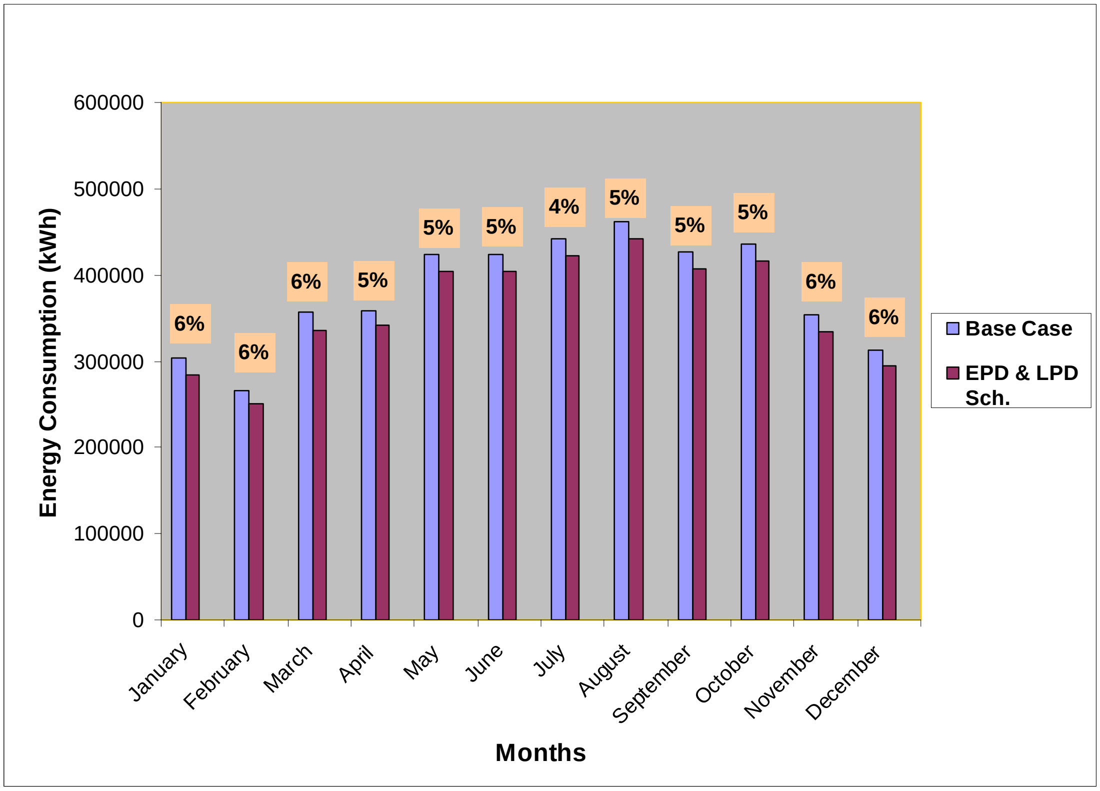

Figure 5.5: Comparison of monthly energy consumption between Schedule of Lighting & Equipment and Base case

From Figure 5.5, on an average, a 5% electric energy savings for each month was achieved.

Low Cost Measures

These are measures that can be implemented for building alterations or modifications and thus, extra cost is required for their implementation.

ECM # 4: Insulated Wall

For the building under study, polyutherene insulation of 50mm thickness is used in walls. The U-value of walls used for the existing building is 0.35W/m^{2}C. As an energy conservation measure, polyutherene insulation of 75mm thickness was tried using the DOE 4.0 simulation program. With the use of that type of insulation, the new U-value of walls was reduced to 0.26W/m^{2}C. As can be seen from the comparison between the existing building and this ECM, only 1% of electric energy can be saved using this ECM which will not be practical and cost effective. For the existing building, it is not practical to replace existing insulated walls with more insulated walls. Therefore, current level of insulated walls is considered to be sufficient. The results are shown graphically in Figure 5.6.

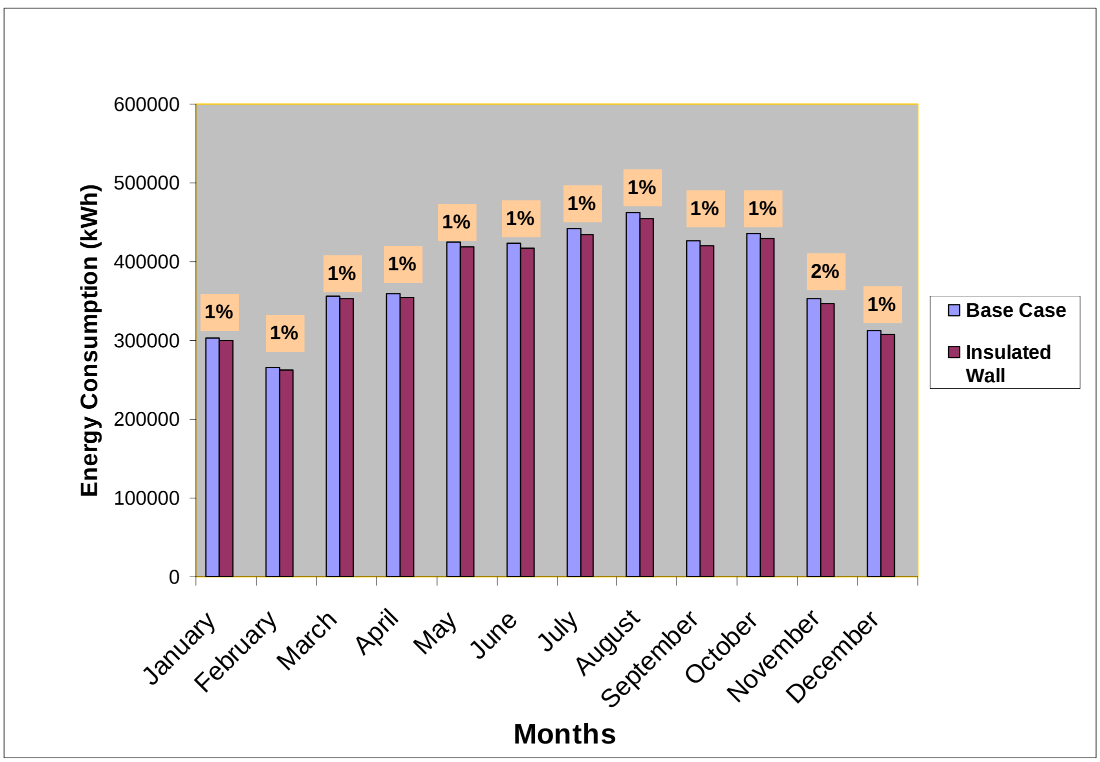

Figure 5.6: Comparison of monthly energy consumption between insulated wall and Base case

ECM # 5: Insulated Roof

For the existing building, polyutherene insulation of 50mm thickness is used for roof construction. The U-value of the roof is 0.35W/m^{2}C. As an energy conservation measure, polyutherene insulation of 75mm thickness was tried using the DOE 4.0 simulation program. With the use of that type of insulation, the new U-value of the roof was reduced to 0.26W/m^{2}C. From the results, less than 1% energy savings was achieved annually and this ECM cannot be used because the current roof system cannot be replaced by more insulated roof and this ECM will not be practical. The results are shown graphically in Figure 5.7.

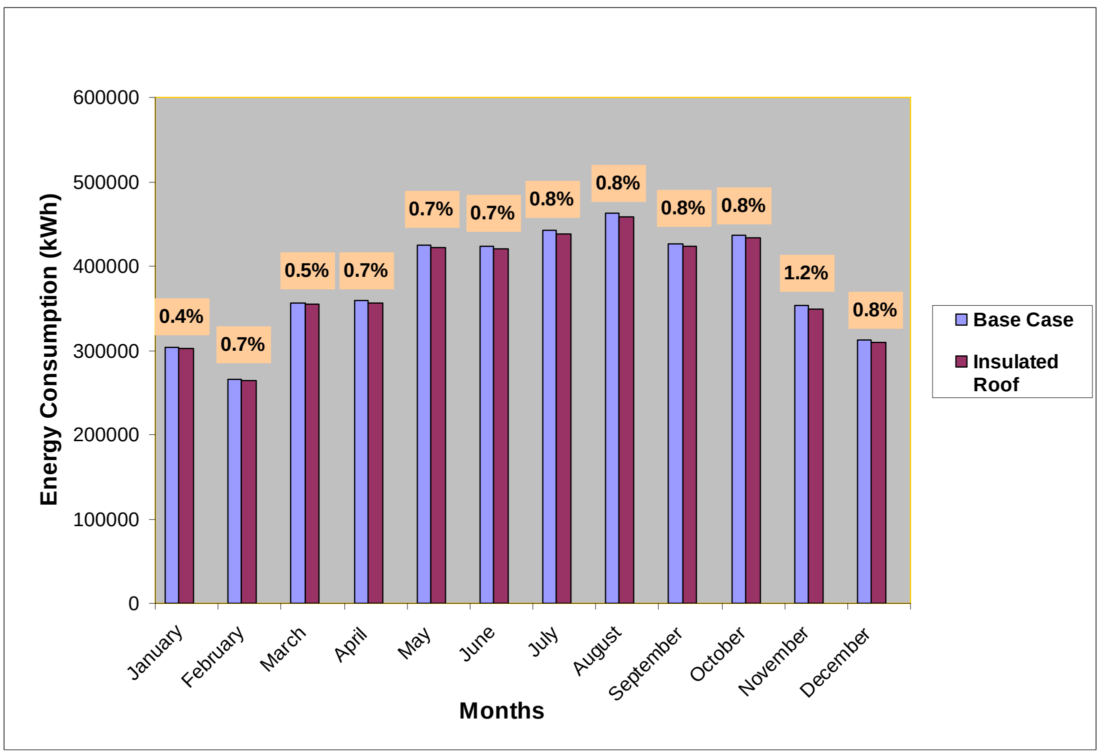

Figure 5.7: Comparison of monthly energy consumption between insulated Roof and Base case

ECM # 6: More Efficient Glazing System

Using more energy efficient windows (high R-value, low emissivity glazing, air tight etc) can be beneficial in both reducing the energy use and improving the indoor comfort levels.

For the existing building, double glazed window is used with the U-value of 3.5W/m^2C. The shading coefficient used is 0.3 and the solar transmittance used is 0.7 for base case. As an energy conservation measure, the existing glazing system was replaced using a simulation program with a low emittance double glazed window. Details are shown in Table 5.8.

Table 5.9: Specifications for the glazing system

Base Case (Double Glazed 6/12/6mm)	**Low Emittance Glazing (Double Glazed 6/12/6mm)**
U=3.5 W/m2K	U=1.8 W/m2K
SC=0.3	SC=0.14
SHGC=0.26	SHGC=0.12
Trasmittance=0.7	Trasmittance=0.7
Colour=blue	Colour =silver

The results for the use of low emittance double glazed window are shown graphically in Figure 5.8.

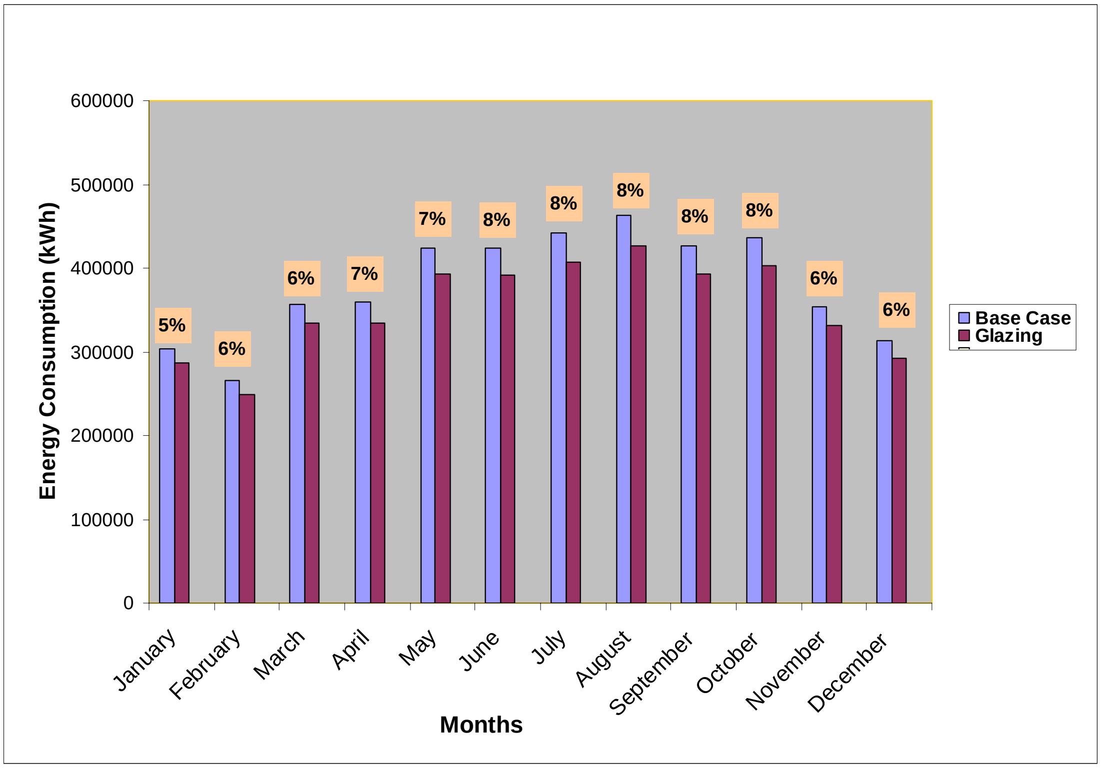

Figure 5.8: Comparison of monthly energy consumption between Glazing and Base case

From the Figure 5.8, it indicates that on an average, a 7% reduction in energy consumption was achieved every month. In summer months, an 8% reduction was achieved using this glazing system. Such savings during summer are achieved because large area of glass is used in the building. The glazing system plays an important role in energy use pattern for the building and for reducing the internal heat gains. It is not practical to apply this glazing system for existing building. However, this ECM can be applied for similar types of office buildings using a large area of glass but the cost factor has to be taken into consideration for applying this glazing system.

ECM # 7: Energy Efficient Lamps

Lighting for a typical office building represents on the average 40% of the total electrical energy use [25]. There are a variety of simple and inexpensive measures to improve the efficiency of lighting systems. These measures include the use of energy efficient lighting lamps and ballasts, the addition of reflective devices and delamping (when the luminance levels are above the levels recommended by the standards).

For the existing building, 40 watts fluorescent lamps were used. According to ASHRAE standard [39], there are 34 watts energy efficient lamps. As an energy conservation measure, fluorescent lamps with the power of forty (34) wattage were used. The monthly electric energy savings are shown graphically in Figure 5.9.

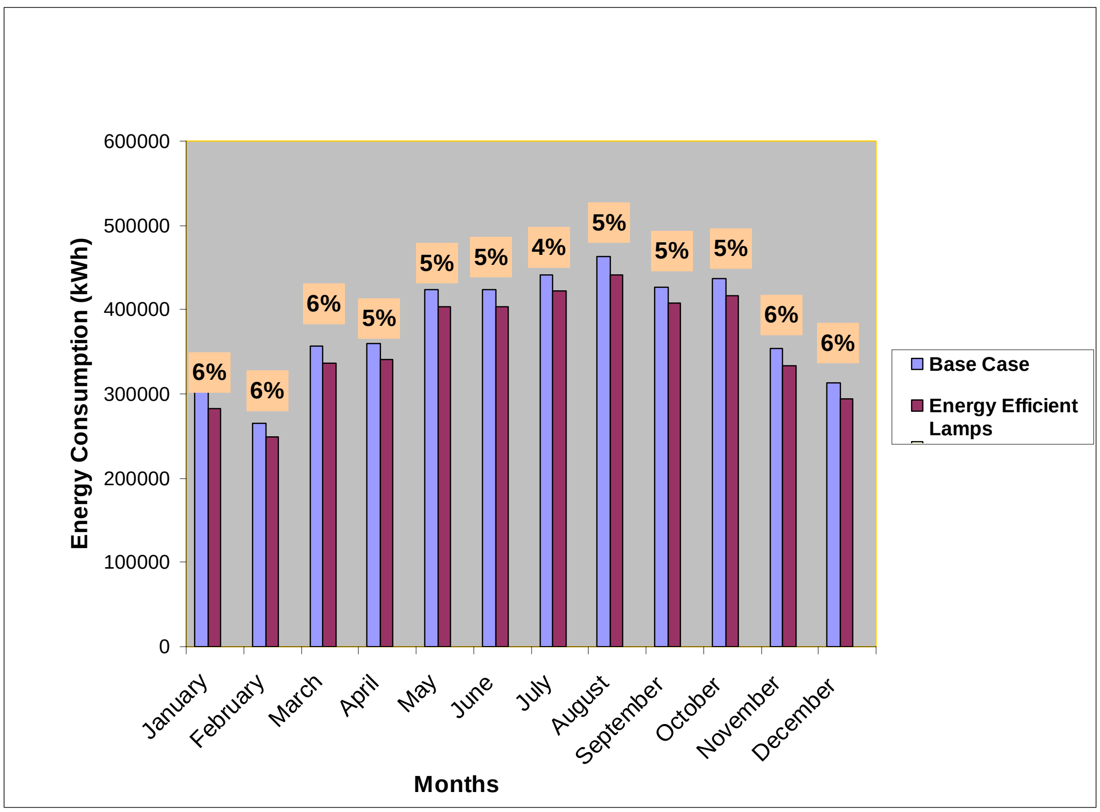

Figure 5.9: Comparison of monthly energy consumption between Energy Efficient lamps and Base case

From Figure 5.9, on an average, a 4.5% reduction in energy consumption is achieved especially in summer months. For the existing building, it's difficult to replace all lighting lamps and it will also be costly so these energy efficient lamps can be kept in storage and whenever there will be any fused or burned lamps, these can be replaced with energy efficient lamps.

Major Investment Measures

These measures require major investment in terms of cost for their implementation. These measures can be implemented through system renovation or retrofitting to the office buildings.

ECM # 8: Replacement of Constant Air Volume with Variable Air Volume System

In the constant air volume (CAV) system, all AHU fans operate with constant speed. They supply conditioned air through a constant volume air supply system to the conditioned zones. The system is designed to supply enough air to cool the building under design conditions. As an energy conservation measure, changing the system to a variable air volume (VAV) system reduced the amount of air supply by all AHU’s and resulted in less energy to condition the various zones. Variable speed drive fans are used in the VAV systems to apply the variable air volume system to the existing building by using simulation program, rezoning was done on the ground, first and fifth floors of the building.

On the ground floor, a variable air volume (VAV) system was applied to the canteen, the advertisement section, the auditorium and the meeting room. On the fourth floor, this system was applied to the administration section and the meeting room. On the fifth floor, the variable air volume (VAV) system was applied to the small office and the three meeting rooms. The results are shown graphically in Figure 5.10. On an average, a 13% reduction is energy consumption has been achieved for the summer months. This ECM can be used more effectively in similar office buildings which are under construction.

ECM # 9: More Efficient Reciprocating Chillers

Chillers are the main part of HVAC systems and play an important role in energy use. In the existing building, air cooled reciprocating chillers were used. As an energy conservation measure, more energy efficient air cooled reciprocating chillers with higher coefficient of performance (COP) of 3.06 were used and the impact of more energy efficient reciprocating chillers on energy use is evaluated using a DOE 4.0 simulation program.

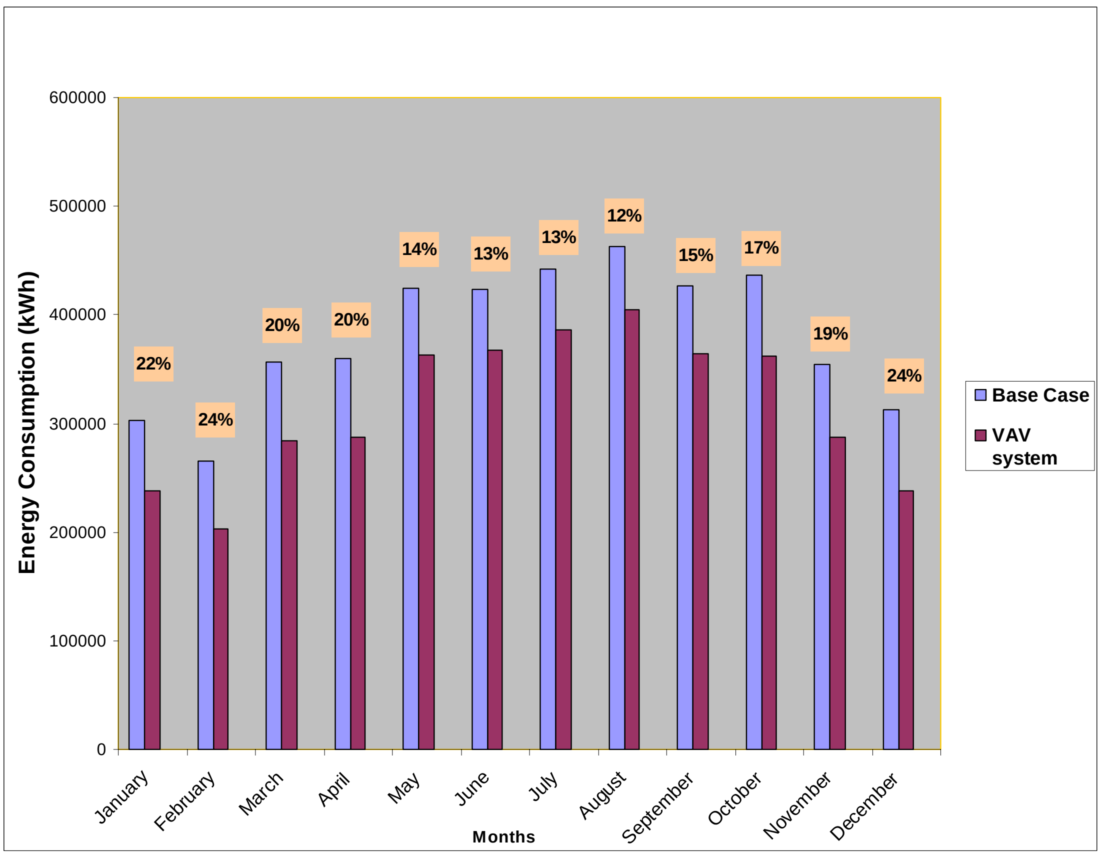

Figure 5.10: Comparison of monthly energy consumption between Variable Air Volume System and Base case

An annual energy savings of about 10% was achieved using more efficient reciprocating chillers with the coefficient of performance (COP) of 3.06 and results are shown graphically in the Figure 5.11. From the Figure, an energy savings of up to 11% has been achieved especially in summer months. These results are based on the specifications obtained from manufacturer's catalogue of carrier air-conditioning company (see Appendix E) which is manufacturing all kinds of chillers through out the world including Saudi Arabia. This ECM might be feasible to apply to the existing building when the retrofitting of existing systems is deemed necessary and can also be applied to similar types of office buildings which are in the design stage or under construction.

Annual Energy Use for Combined ECMs

The annual energy use for the combined energy conservation measures (ECMs) is shown in Figure 5.12.

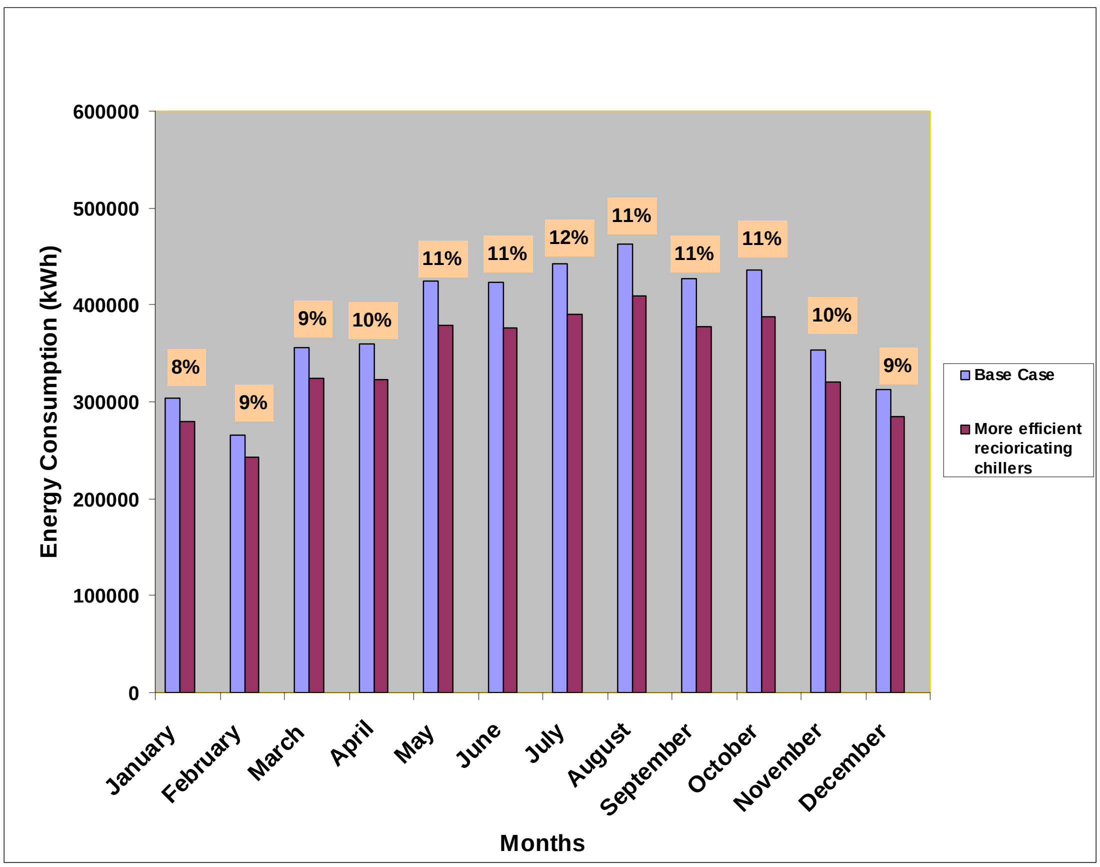

Figure 5.11: Comparison of monthly energy consumption between more efficient reciprocating Chillers and Base case

From the Figure 5.12, energy savings of up to 27% can be achieved annually by using the variable air volume systems and more efficient reciprocating chillers only. As discussed above, the variable air volume system can be used in the existing building by doing rezoning.

Energy savings of up to 15 % can be achieved annually using more insulated roofs and walls, more efficient glazing system and energy efficient lamps. As discussed above, energy efficient lamps can be used gradually in the existing building but from practical point of view, more roof and wall insulation and new glazing system are not practically feasible in the existing building; however these can be applied for similar types of office buildings. Energy savings up to 13% can be achieved annually using scheduling of lighting and equipment, set point temperatures and night time set back mechanism and these measures don't cost any and falls under operational measures. These measures can be applied to the existing building.

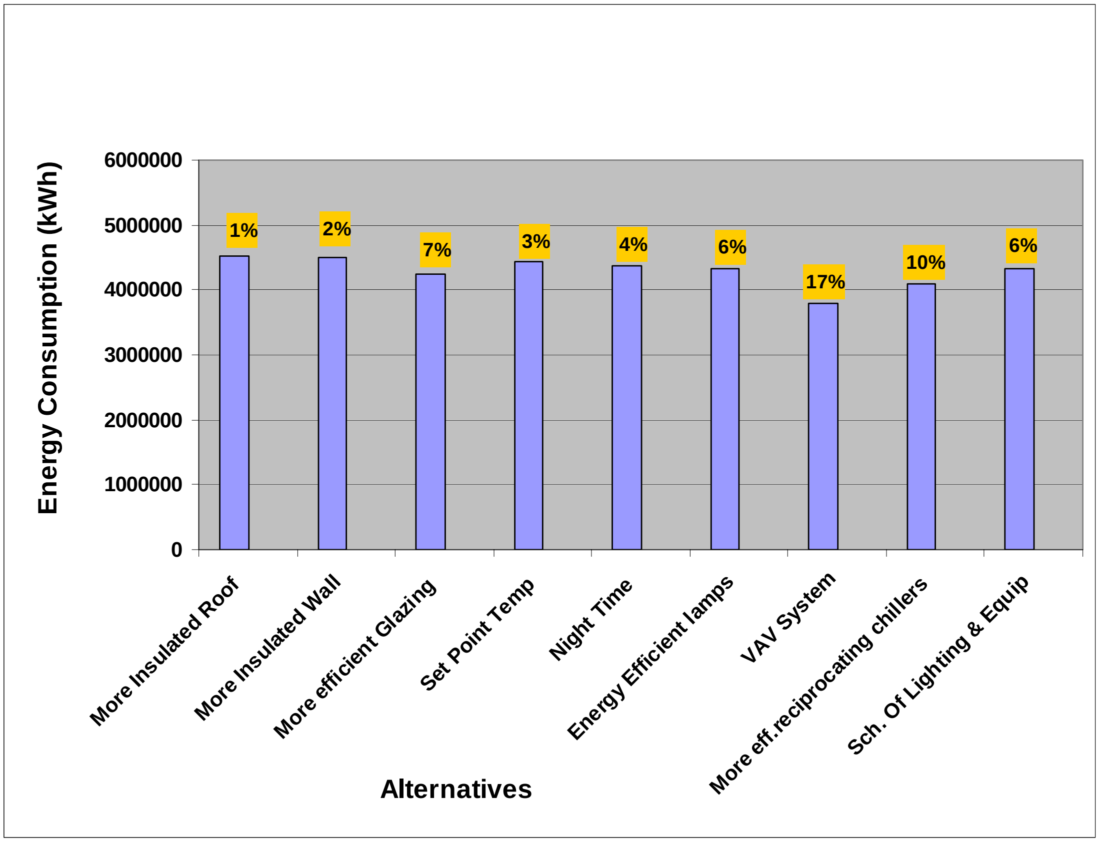

Figure 5.12: Annual Energy use for Combined Energy Conservation Measures

Conclusively, all no cost measures can be applied to the existing buildings which include scheduling of lighting and equipment, set point temperatures and night time set back mechanism. About 13% of electric energy can be saved annually. About low cost measures, only energy efficient lamps can be used gradually to the existing building whenever, there are fused or burned lamps. An annual energy savings of up to 6% can be achieved. About high investment cost measures, variable air volume system can be implemented by doing rezoning to the existing building and an electric energy savings of about 17% can be achieved annually. Finally, by implementing all these ECMs, about 36% of electric energy can be saved annually.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

In the current research, the impact of HVAC systems selection and operation on energy conservation in an office building was studied. The objectives were to determine the efficient type of HVAC system, to determine operational measures, to prioritize the feasible, practical and operational measures that can produce significant savings on energy cost and finally to develop guidelines for HVAC systems design and operation that can provide greater occupant comfort with potentially reducing energy consumption in similar office buildings in hot and humid climates of Saudi Arabia. Based on the results of questionnaire analysis, field measurements and energy simulation, the following conclusions are made:

1. More than 80% of the surveyed respondents have expressed their satisfaction with thermal conditions which include air temperature, air humidity and air velocity. However, 44% of the surveyed respondents on the first floor have shown their dissatisfaction with air temperature.
2. Most of the surveyed respondents of the building have indicated that they cannot adjust the thermostat for changing indoor air temperature and have shown their great concern for having the thermostat within their range for adjusting indoor temperature change.
3. More than 50% of the surveyed respondents have indicated that they feel inadequate ventilation for some time for performing their work.
4. More than 80% of the surveyed respondents have indicated that they don’t feel job stress due to thermal discomfort. However, 70% of the surveyed respondents on the ground floor have indicated that they feel job stress for some time due to thermal discomfort.
5. More than 80% of the surveyed respondents have indicated that:

I. They don't have frequent complaints about air-conditioning at their work places.
II. They often get quick response from maintenance department.
III. They don't have to use pedestal fan for more cooling at their workplaces.
IV. They have adequate lighting at their work places.
V. They don't feel visual discomfort due to glare from the lights.
VI. They don't feel discomfort from noise coming from equipments

6. All the surveyed respondents of the building have indicated that they don't have interior shading for windows at their workplaces and they don't have operable windows for getting fresh air.
7. About 21% of the surveyed respondents have indicated that they feel lack of voice privacy at their work places.
8. The measured air velocity was within the comfort range of 0.127-0.23m/s for most spaces in the building.
9. All zones of the building are within the comfort range (i.e. 23^{o}C to 26^{o}C) for air temperature and 30-70% air humidity for the summer months (June, July, August and November). However, it is found that there were few zones on the fourth floor where the air temperature of up to 27.5^{o}C were recorded from 4am to 8am where there is no occupancy at this period of time. It was also found that there were few zones on the fifth floor where the air temperature was recorded at 27^{o}C most of the time. The reason for this is because these zones were closed most of the time and were open for some meeting purposes only. It is also found that air humidity for the month of July of up to 90% was recorded in most zones of the building at night time where there was no occupancy.
10. For the winter month of December, both air temperature and humidity were within comfort range except for one zone on ground floor (i.e. the developing and telephone section) where air temperature was recorded at 19^{o}C between 3am to 6am in the morning where there was no occupancy at these night hours.

11. Increasing the current polyutherene insulation from 50 mm to 70 mm thickness for walls and roof construction revealed annual electric energy savings of only 3%. However, it is not practical to change wall and roof insulation for the existing building and the extra cost issue has also to be taken into consideration. Current level of insulation is, therefore, considered to be sufficient.

12. Using double glazed window with a U-value of 1.8 W/m^2C instead of the U-value of 3.5 W/m^2C for the existing building revealed an annual electric energy saving of about 7% which can be considered for new building or for retrofitting of the existing building.

13. Using set point temperatures for summer and winter at 26^oC for summer and at 20^oC for winter revealed an annual electric energy savings of 3%. This ECM is operational and does not cost anything.

14. Using night time set back mechanism; the indoor air temperature was set at 28^oC for summer and at 16^oC for winter for night time from 11pm to 7am in the morning revealed an annual electric energy saving of 4%. Again, this ECM is operational and doesn't cost anything.

15. Using a variable air volume system instead of the current constant air volume system resulted in an annual electric energy saving of 17%. For the existing building, each zone is served by a constant air volume system. The variable air volume system can be applied to the existing building by doing rezoning.

16. Using more energy efficient reciprocating chillers instead of current reciprocation chillers, an annual electric energy was reduced by 10%. It can be applied to the existing building when the retrofitting is deemed necessary and can also be applied to similar types of office buildings which are in the design stage or under construction.

17. Using 34 watts energy efficient lamps can reduce an annual energy saving by 6%. However it is not practical and cost effective to replace all lamps with energy efficient lamps. They can be replaced gradually as they burn out over time.

18. By adjusting the schedule of lighting and equipment during unoccupied or low occupancy periods revealed an annual electric energy saving of 5%. Again, it is operational measure, and it doesn't cost any extra thing.
19. Using the high investment cost measures as a variable air volume system and water centrifugal chillers revealed an annual electric savings of 56%. Using the low cost measures as most insulated walls and roof, more efficient glazing system and energy efficient lamps revealed an annual electric savings of 15%. By using no cost measures as set point temperatures, night time set back and adjusting the schedule of lighting and equipment revealed an annual electric savings of up to 13%.

Conclusively, majority of occupants are satisfied with building's overall function in terms of thermal comfort and their workplace conditions. However, there were some zones of the building where the indoor air temperature and humidity was found to be above comfort range. An annual electric energy savings of up to 36% can be achieved for the existing building by applying no cost, low cost and high investment measures.

6.2 Recommendations

Based on the conclusions of this research work, the following recommendations are made for the existing office building as well as for any future project:

1. There should be interior shading such as venation blinds over the windows to help controlling direct solar radiation.
2. There should be operable windows for getting fresh air during moderate weather conditions where the HVAC system can be turned off and thus considerable electric energy can be saved annually.
3. There should be sufficient air movement and air distribution at the workplaces for performing work in an efficient manner.

4. It is strongly recommended that the following set point temperatures should be used for working hours during summer and winter for energy conservation purposes:
   Indoor air temperature: 26^{o}C for summer, 20^{o}C for winter
5. It is strongly recommended that a night time setback mechanism during unoccupied periods at least from 11pm to 7am in the morning with indoor air temperature at 28^{o}C for summer and 16^{o}C for winter should be used.
6. It is also recommended that the schedule of lighting and equipment should be adjusted so that they are turned off during unoccupied or low occupancy night hours, during lunch and prayer timings.
7. It is recommended that a continuous dimming control should regulate the light level so that the luminance level inside the zone remains constant. In this way, the electricity consumption of the building can be significantly reduced. Occupancy sensors should be considered for lighting system.
8. It is recommended that the actual space temperature should be monitored frequently and care should be taken for the proper temperature and humidity settings because improper control of temperature and humidity may result in thermal discomfort.
9. Different glazing systems were used as alternatives and it is recommended to use low emmitance double glazed windows for energy efficiency especially in new constructions.
10. It is recommended that energy efficient lamps of fluorescent type having a power of 34 watts should be used for similar types of buildings. However, for existing buildings, it is recommended that these energy saving lamps should be used when lamps are burned or fused.
11. Air conditioning systems play an important role in energy consumption especially in summer. As the weather becomes extreme in summer and mild in winter, it is strongly recommended that a variable air volume (VAV) system should be used as system renovation and by doing rezoning for the existing building and best preference for future similar office buildings.

12. Chillers are major contributors of annual energy consumption. It is recommended that more energy efficient air cooled reciprocating chillers should be used for energy savings. It can be applied to the existing building as well as to the future similar office buildings taking into consideration the cost factor.

6.3 HVAC Systems Design, Operation & Maintenance Guidelines

General guidelines have been formulated for HVAC systems design, operation & maintenance for office buildings in hot and humid climatic conditions of Saudi Arabia. The proposed guidelines have been developed based on conclusions and recommendations of the current research work and with the consultation of ASHRAE standards 100.3-1985 and 90.1-1989 and summarized in Table 6.1A.

1. Separate HVAC systems should be considered to serve areas expected to operate on widely differing operating schedules or design conditions. It can be applied to the existing building using a variable air volume system by doing rezoning. About 16% of electric energy can be saved annually. It is also applicable to the future similar office buildings.

2. Controls should be provided to allow systems to operate in occupied mode and unoccupied mode. In the occupied mode, controls should provide for a gradually changing control point as system demands change from cooling to heating. In the unoccupied mode, ventilation and exhaust systems should be shut off if possible. This can be applied to existing buildings because there are some zones which are not occupied daily such as women section, auditorium and Meeting rooms.

3. Night setback of building temperatures should be accomplished by automatic means. Optimum night setback of the building temperatures should be determined by the building operator in regard to the required morning operating time to bring the building back to daytime desired occupancy temperature.

4. Each HVAC system shall include at least one temperature control device. For existing building, about 4% of annual electric energy can be saved by using temperature control device. Each temperature control device should have set point temperature at $26^{o}C$ for summer and $20^{o}C$ for winter
5. The supply of zone cooling and heating should be sequenced to prevent the simultaneous operation of cooling and heating systems for the same space.
6. For fan systems which provide a constant air volume whenever the fans are operating, the power required by the motors for the combined fan system at design conditions shall not exceed 0.8 W/cfm of supply air.
7. Start up and shut-down procedures should be established to assure the efficient use of energy consuming systems. The established procedures should reflect a cyclic starting schedule for equipment with large starting currents and the minimum time required to bring the system on the line with minimum load peaking. This could be applied to the existing buildings as well as to the similar future office buildings.
8. HVAC systems shall be equipped with automatic controls capable of accomplishing a reduction in energy use through control setback or equipment shutdown during periods of non-use or alternate use of the spaces served by the system. For existing buildings, it could also be applicable for zones which are used occasionally.
9. By experimentation, the building operator should determine an allowable reduction time of heating and cooling equipment operation by taking the advantage of thermal lag, both within the buildings as well as external piping. On days expected to be very hot, the building can be cooled below normal during night and early morning hours, allowing the inside air temperature to rise during the later time of the day. The cooling equipment can be shut off altogether somewhat prior to the closing time. This practice reduces the overall load on the cooling equipment, as well as the amount of power consumed during the peak load period. This could be applicable to existing buildings as well as for future office buildings.

10. For unoccupied periods (Weekends, Holidays and Nights), during heating seasons, HVAC systems should be shut off or maintained temperatures should be permitted to fall to the lowest possible level consistent with the temperature protection of water lines and processed or stored materials within the conditioned space. During the cooling seasons, HVAC systems should be shut off or maintained temperatures should be permitted to raise the highest possible level consistent with temperature protection of processed or stored materials within the conditioned space.

11. All HVAC air distribution and water distribution systems should be zoned to obtain maximum energy conservation, by reducing capacity or causing a shut down when the zoned area requires less capacity or no conditioning. This can be applicable to existing buildings where separate HVAC system is used for each zone and maximum energy conservation could be obtained.

12. When energy can be conserved, one or more of the following should be provided:

- Consider installations of time switches and manual override timers in control circuits to enable scheduling of cooling and heating operations of fans, and refrigeration equipment etc.
- Consider adding time switches on self contained cooling and heating units for automatic shutoff.
- Adjust automatic timers or consider adding time switches to deactivate cooling and heating systems during evening, weekends, holidays and other periods when the building is unoccupied.
- Determine if the chiller plant can be shut down when the outdoor temperature is below 10^oC.
- Consider the use of optimizing controls to operate equipment in most efficient modes of operation.

13. Operation of an energy efficient system is totally dependent upon continuous maintenance of each and every component in its optimum performing condition. Consideration should be given to the following if applicable [40]:

a) **Fans**

- Check for excessive noise and vibration. Determine cause and correct as necessary.
- Keep fan blades clean.
- Inspect the lubricant bearings.
- Inspect drive belts; measure and adjust tension to manufacturer's recommendation

b) **Pumps**

- Check for seal or packing wear which can cause excessive leakage. Repack to avoid excessive water wastage and erosion.
- Inspect and lubricate bearings.
- Inspect drive belts, measure and adjust tension to manufacturer's recommendation.

c) **Motors**

- Check the alignment of motor to equipment driven. Align and tighten as necessary.
- Keep motors clean.
- Eliminate excessive vibration.
- Replace worn bearings.

d) **Air Handling Equipment**

- Inspect and/or test ductwork for air leakage. Seal all leaks by applying liquid sealant, sealant plus tape, taping gaskets, or caulking.
- Inspect mixing dampers for proper operation. Adjust as necessary.

- Clean and remove obstructions from all room air outlets and inlets (diffusers and grills). They should be kept clean and free of all dirt and foreign materials.

6.3.1 Building Envelope Guidelines

Proposed guidelines for building envelope and lighting have been developed based on conclusions and recommendations of the current research work and with the consultation of ASHRAE standards 100.3-1985 and 90.1-1989 and summarized in Table 6.1B

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1. Operable windows should be considered to allow for occupant-controlled ventilation. When using operable windows, the design of the building mechanical system must be carefully executed to minimize unnecessary HVAC energy consumption and building operators must be cautioned about the improper use of operable windows.

2. All the windows in the exterior envelope of buildings that are mechanically cooled should be fitted with some form of solar shading to reduce solar heat gain. The following alterations or additions or both should be considered:

   - Solar screen
   - Interior draperies
   - Venetian blinds.

   This can be applicable to existing buildings as well as new constructions for reducing solar heat gain.

3. Infiltration reduction should be accomplished through design details that enhance the fit and integrity of the building envelope joints in a way that may be readily achieved during building construction. This includes infiltration control by caulking, weather stripping, and revolving doors with construction meeting specifications.

4. To achieve control of the building envelope as a membrane and to simultaneously achieve occupant comfort in the perimeter zones, many of the traditional skin components must be used (insulation, mass, caulking and weather stripping). However, other factors should also be considered such as operable solar shading devices and heat loss and gain of glazing systems, when designing the HVAC system.

5. Consider building attributes such as building function, form, orientation, window/wall ratio, and HVAC system type early in the design process.

6.3.2 Guidelines for Lighting

1. Consider the energy efficient lamps of fluorescent type with a power of 34 watts. By using this type of lamps, about 6% of electric energy could be saved annually. This can be applied to similar types of any office building in future.

2. Consider day lighting along with the proper use of controls so that the savings from electric lighting can be realized. Design should be sensitive to window glare, sudden changes in luminance and general user acceptance of day lighting controls. Window treatment (blinds, drapes, and shades) and glazing should be carefully selected to control direct solar penetration and luminance extremes while still maintaining view and daylight penetration. This could be applicable to existing buildings as well as similar office buildings in future.

3. All lighting controls shall be located so as to be readily assessable to personnel occupying or using the space.

4. The minimum energy management capabilities should provide the capability to turn lighting systems ON or OFF based on time schedules such as occupancy sensors.

REFRENCES

1. C. Robert, Rosealer (1998) "HVAC Maintenance & Operation Handbook" McGraw-Hill Book Company New York.

2. R. Taesler (1991). "Climate and Building Energy Management", Energy and Buildings, Vol. 15, pp 599-608

3. J. Trost (1990), “Efficient Buildings-2”, Heating and Cooling Grisp Publications Inc.

4. S. M. Hasnain, S. H. Alawaji, A. R. Al-Ibrahim. (1999) "Applications of Thermal Energy Storage in Saudi Arabia", International journal of Energy Research, Vol. 23, pp 117-124.

5. H. William (1994) "HVAC Design Criteria Options, Selection". R.S Means Company, Inc; Miami.

6. S. Gupton (1996) "HVAC Controls and Operation & Maintenance", McGraw-Hill Book Company New York.

7. E. N. Angevine, and J. S Fair (1995) "HVAC systems" Energy Management Handbook. McGraw-Hill Book Company New York

8. R. H. Howell, H. J. Sauer, Jr. and W. J. Coad (1998)." Principles of Heating, Ventilation and Air-Conditioning, American Society of Heating, Refrigeration and Air-Conditioning Engineers (ASHRAE)", Inc, Atlanta, Georgia.

9. F. Engdahl, D. Johansson (2004). "Optimal Supply Air Temperature with respect to Energy Use in a Variable Air Volume System" Energy and Buildings, Vol. 36, pp. 205-218.

10. M. Ardehali, T. F.Smith (1997) "Evaluation of HVAC System Operational Strategies for Commercial Buildings" Energy Conversion and Management, Vol. 38, No. 3, pp.225-236.

11. V. S. Anantapantula, H. j. Sauer Jr., P.E. (1994) "Heat Recovery and the Economizer for HVAC Systems." ASHRAE Journal, pp. 48-52

12. M. P. Maiya. (1996) "Thermal Performance of an Evaporative Cooled Building: Parametric Studies" International Journal of Energy Research, Vol. 20, pp. 465-481.

13. ASHRAE Handbook (2001), Fundamentals, American Society of Heating, Refrigeration and Air-Conditioning Engineers, Inc., Atlanta, Georgia.

14. E. Mayer (1993). "Objective Criteria for Thermal Comfort", Building and Environment, Vol. 24, No. 4, pp 399-403

15. W. Donald, FAIA and L. Kenneth (1983) "Energy-Efficient Buildings, Principles and Practices". McGraw-Hill Book Company New York.

16. M. Carriere, G. J. Schoenau, R.W. Besant, (1999)."Investigation of Some Large Building Energy Conservation Opportunities using the DOE-2 Model", Energy conversion & Management, Vol. 40, pp 861-872.

17. J. A. Clarke (1993) "Assessing Building Performance by Simulation" Building and Environment, Vol. 28, pp. 419-427

18. M. S. Al-Homoud (1997) “Optimal Thermal Design of Office Buildings." International Journal of Energy Research Vol. 21 pp. 941-957.

19. S. M. Hasnain, M. S. Smiai, A. M. Al-Ibrahim, Al-Awaji (1997)"Analysis of Electric Energy Consumption in an Office Building in Saudi Arabia" ASHRAE Transactions Vol. 103, Part I, pp 173-184.

20. S. A. Smiai (1998) “Effective Tools toward Electrical Energy Conservation in Saudi Arabia" Energy conversion and Management Vol. 39, pp.1337-1349.

21. S. M. Hasnain, N. M. Alabbadi (2000) "Need for Thermal Storage Air Conditioning in Saudi Arabia” Applied Energy, Vol. 65, pp. 153-164.

22. P. G. Rousseau, E. H. Mathews (1993) "Needs and Trends in Integrated Building and HVAC Thermal Design Tools", Building and Environment, Vol. 28.No. 4 pp 439-452.

23. E. H. Mathews. , C. P. Botha, D.C Arndt, A. Malan (2001) "HVAC control Strategies to Enhance Comfort and Minimize Energy Usage "Energy and Building Vol. 33, pp. 853-863.

24. O. M. Al-Rabghi, Douglas C. Hittle (2001) "Energy Simulation in Buildings: Overview and BLAST example "Energy conversion and Management, Vol. 42, pp. 1623-1635.

25. M. Krarti (2000) "Energy Audit of Building Systems" CRC Press, New York.

26. E. Gratia, A. D. Herde. (2003) "Design of Low Energy Office Buildings" Energy and buildings, Vol. 35, pp. 473-491

27. M. Santamouris, A. Argirious, C. Balaras and A. Gaglia (1994) "Energy Characteristics and Savings Potentials in Office Buildings", Solar Energy, Vol. 52, pp 59-66

28. M. D. McDiarmid (1997) "Practical Consideration in Monitoring Building Energy Use" ASHRAE Transactions, Vol 101, pp 66-88

29. C. A. Pieper (1994) "Individual Room Temperature Control: A Peaceful Solution to Thermostat Wars", HPAC Journal, pp 97-99.

30. K. W. Tham (1993) "Conserving Energy without Sacrificing Thermal Comfort", Building and Environment, Vol. 28, pp. 287-299.

31. E. H. Mathews, C. P. Botha (2003)-"Improved Thermal Building Management with the Aid of Integrated Dynamic HVAC Simulation" Building and Environment , Vol. 38, pp 1423-1429

32. S. Onaygil , O. Guler (2003) " Determination Of the Energy Saving by Daylight Responsive Lighting Control Systems with an Example from Istanbul ", Building and Environment, Vol. 38, pp. 973-977.

33. M. A. Mahmood, A. E. Ben-Nakhi (2003) "Architecture Performance of Neural networks for efficient A/C control in Buildings" Energy conversion and Management, Vol. 44, pp. 3207- 3226.

34. T. A. Reddy, H. F. Saman, D. E. Claridge, J. S. Haber, W. D. Turner (1997) "Baseline Methodology for Facility-Level Monthly Energy Use"

Application to eight army installation. ASHRAE Transactions; Vol. 103 Part 2,pp 734-742

35. R. Keeney, J. Braun (1997), "Application of Building Pre-cooling to Reduce Peak cooling requirements" ASHRAE Transactions 1997;Vol. 103 Part 1, pp 463-469

36. J. D. Parker (1984) "Energy Conservation Measures" John Wiley & Sons, Inc., New York.

37. ASHRAE Insights. (1998).The Newspaper of the American Society of Heating, Refrigeration and Air-Conditioning Engineers, Inc., Vol. 13, No. 9.

38. Eley Associates of Architectural Engineering Cooperation USA.

39. ASHRAE standard 100.3-1985 “Energy Conservation in Existing Building-Commercial”. American Society of Heating, Refrigeration and Air-Conditioning Engineers, Inc., Atlanta, Georgia.

40. ASHRAE standard 90.1-1989 “Energy Efficient Design of New Buildings except Low-Rise Residential Buildings. American Society of Heating, Refrigeration and Air-Conditioning Engineers, Inc., Atlanta, Georgia.

41. The Dickson ware Software Company (1997-98) USA.

42. Smart Recorder Software Company (1999-2000) Slovakia.

43. K. Nagengast (1999) “A History of Comfort Cooling Using Ice” ASHRAE Journal, Volume 41, No 2, pp 49-57.

44. J. Arnold (1999) “The Evolution of Modern Office Buildings and Air-Conditioning” ASHRAE Journal, Vol. 41, No 6, pp 40-54.

45. ANSI/ASHRAE standard 55-1992 “Thermal Environmental Conditions for Human Occupancy. American Society of Heating, Refrigeration and Air-Conditioning Engineers, Inc., Atlanta, Georgia.

(These references follow the format of the journal “Energy and Buildings”)

Appendix A

Field Measurement Graphs

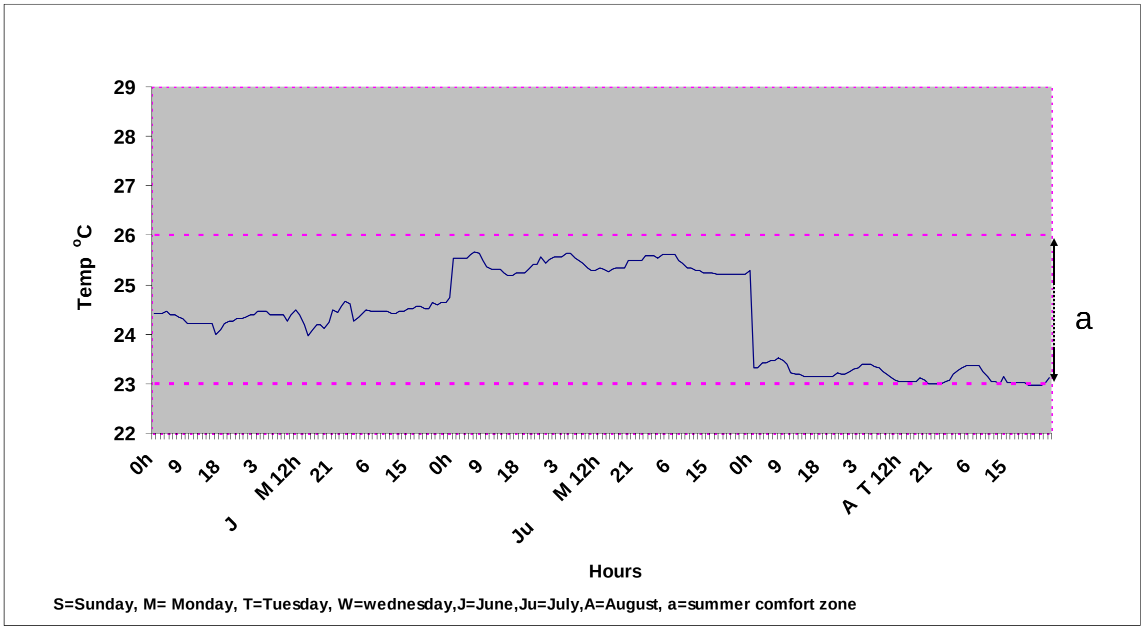


Figure A1: Summer days temperature profile for women section

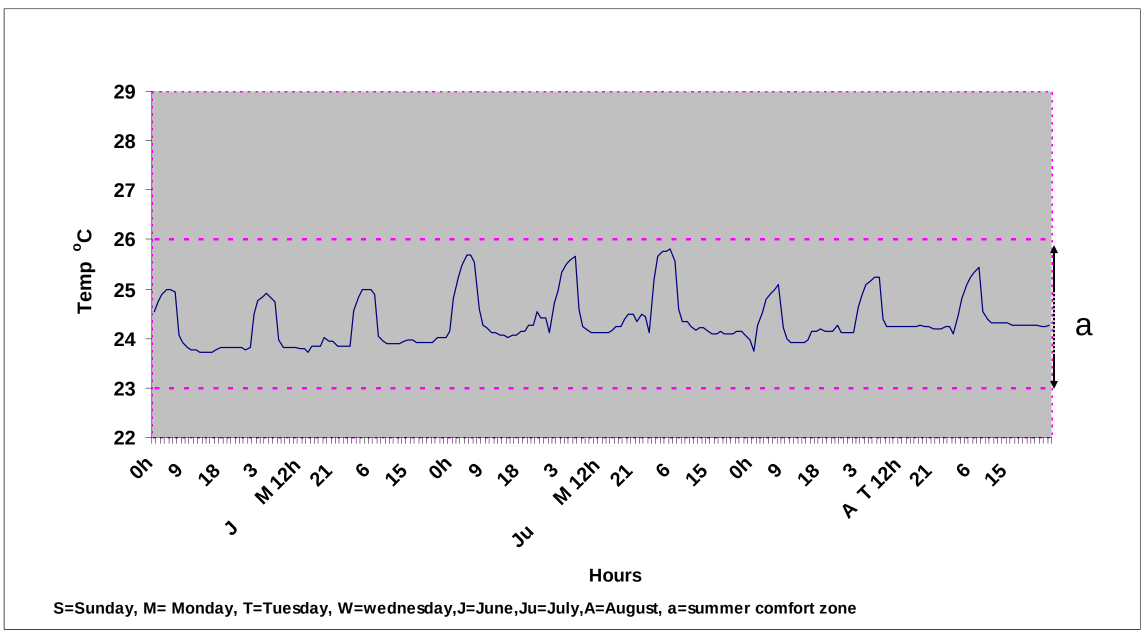


Figure A2: Summer days temperature profile for developing and telephone section

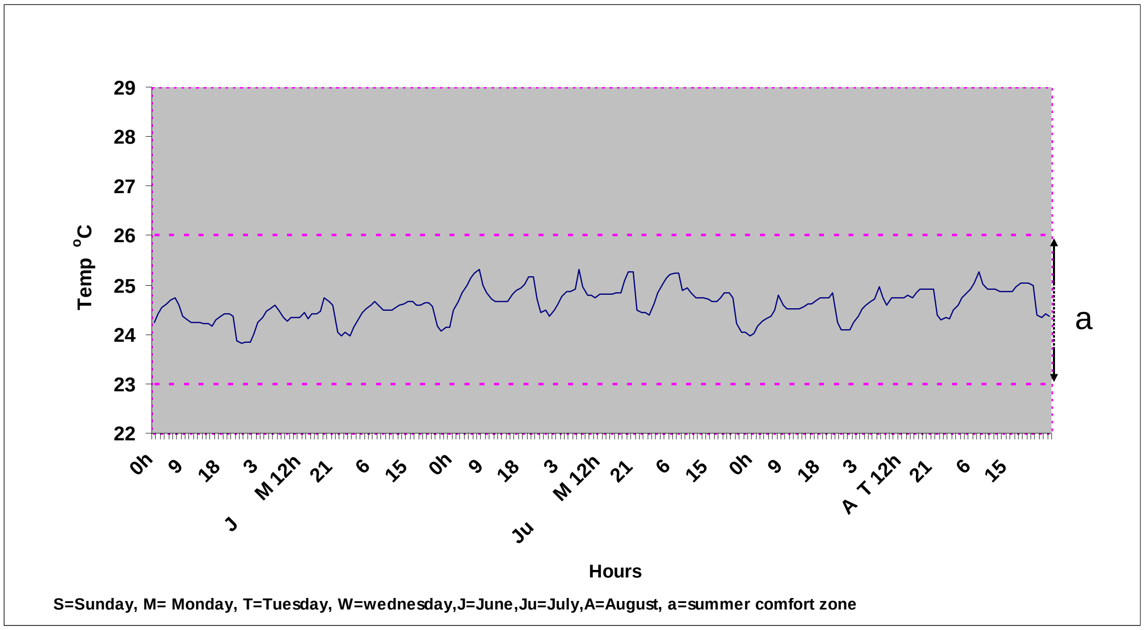


Figure A3: Summer days temperature profile for canteen and traing room section

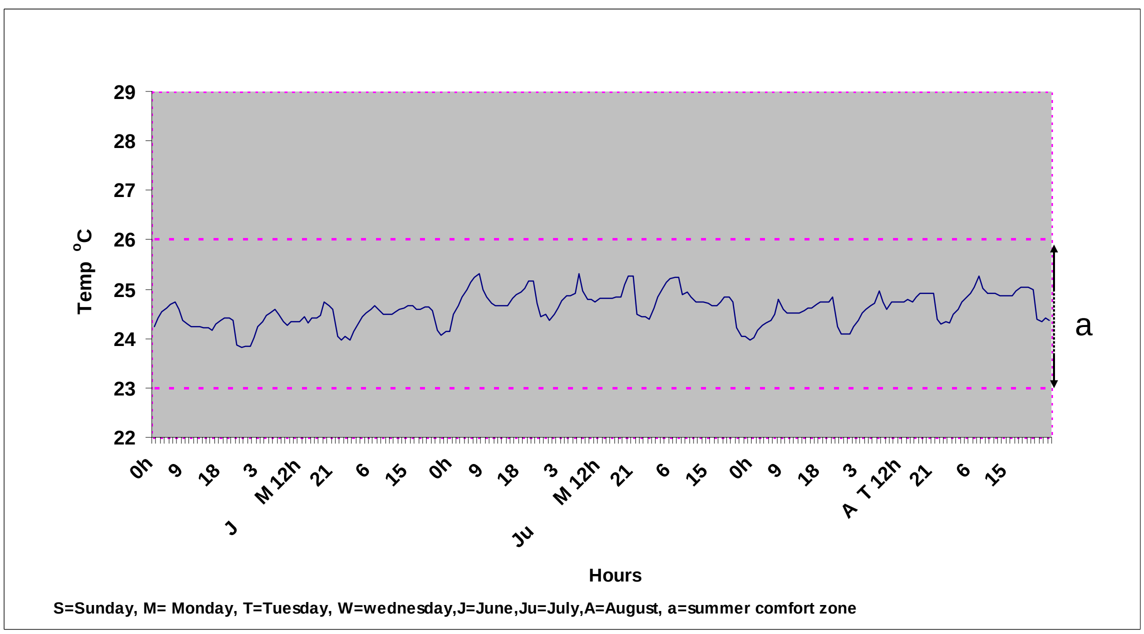


Figure A4: Summer days temperature profile for advertisement section

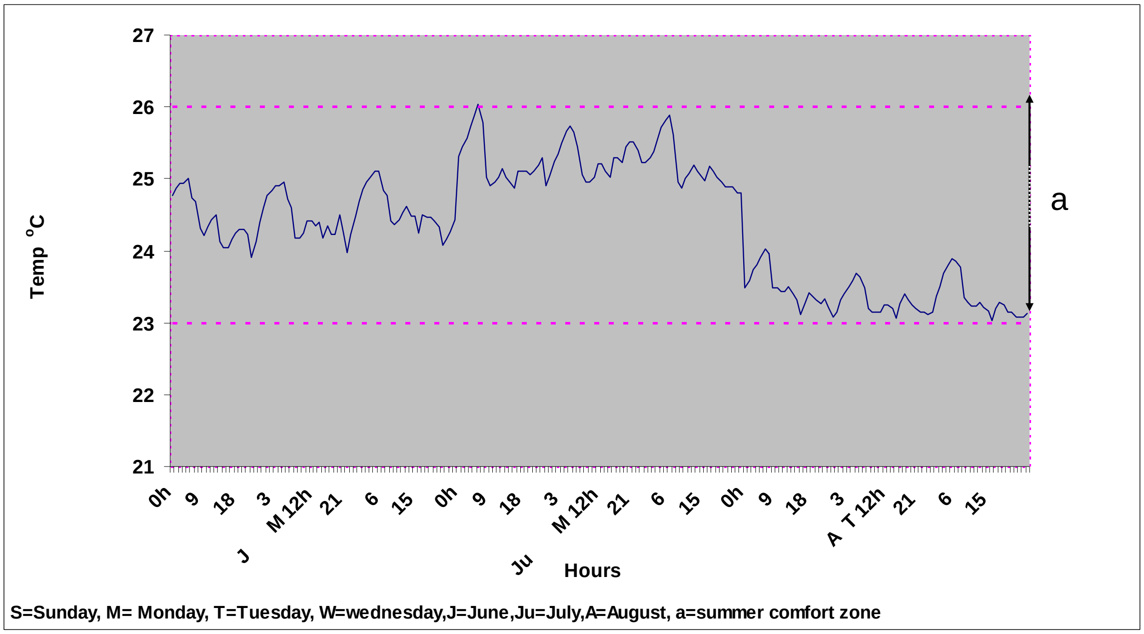


Figure A5: Summer days temperature profile for mosque

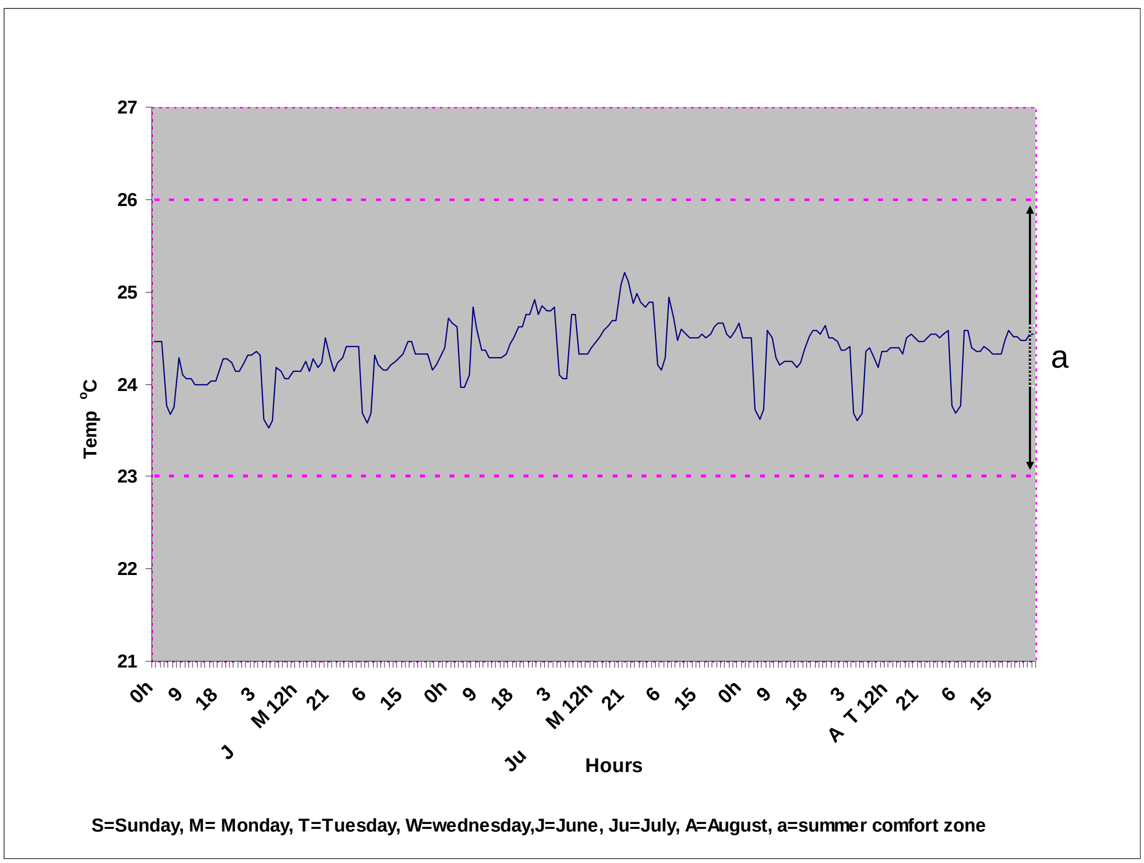


Figure A6: Summer days temperature profile for computer section

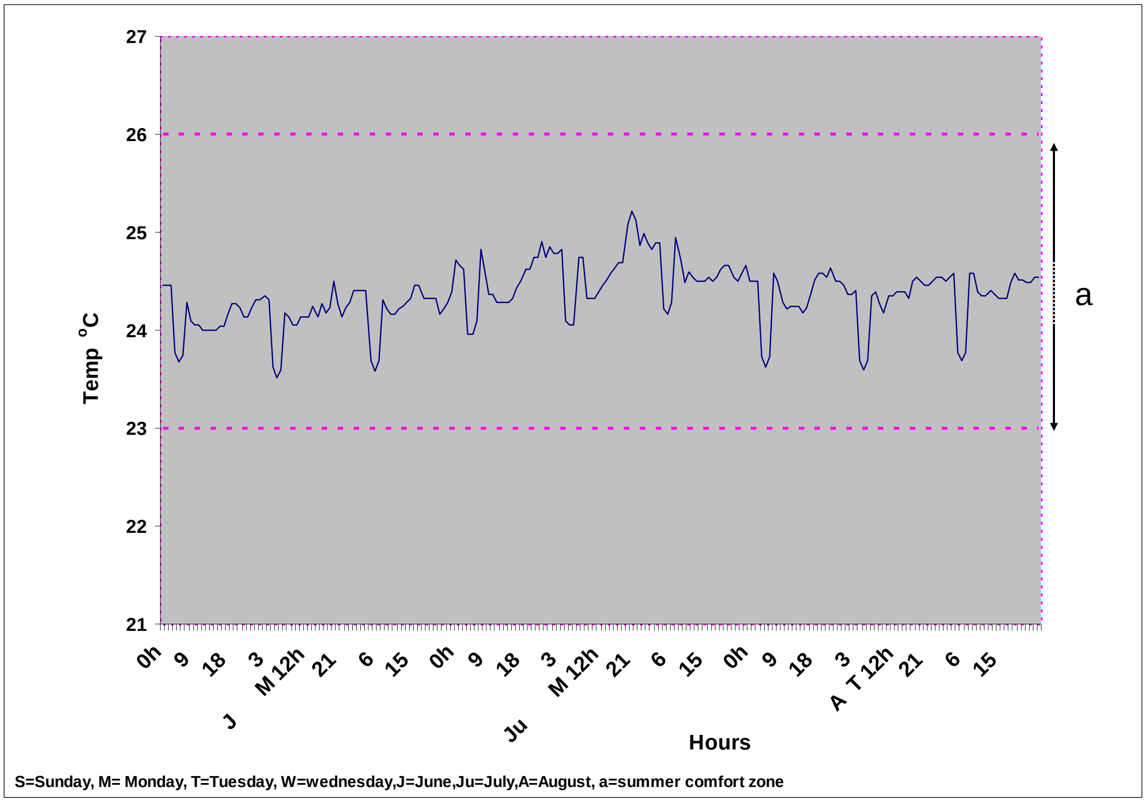


Figure A7: Summer days temperature profile for editing section

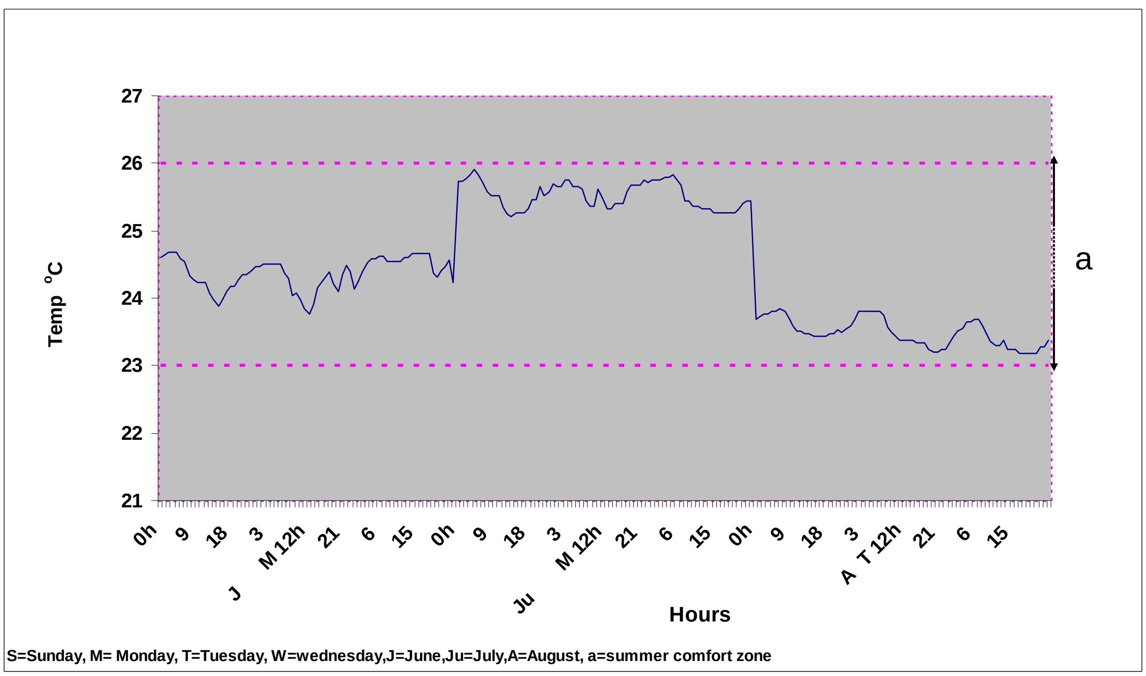


Figure A8: Summer days temperature profile for design & publication section

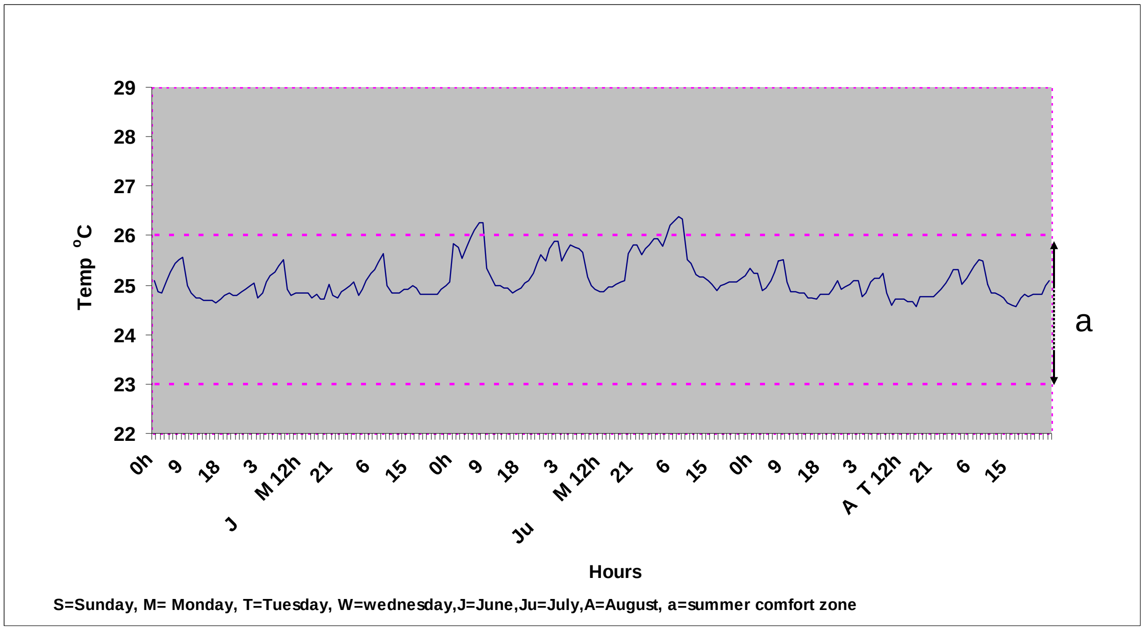


Figure A9: Summer days temperature profile for assistant editor office

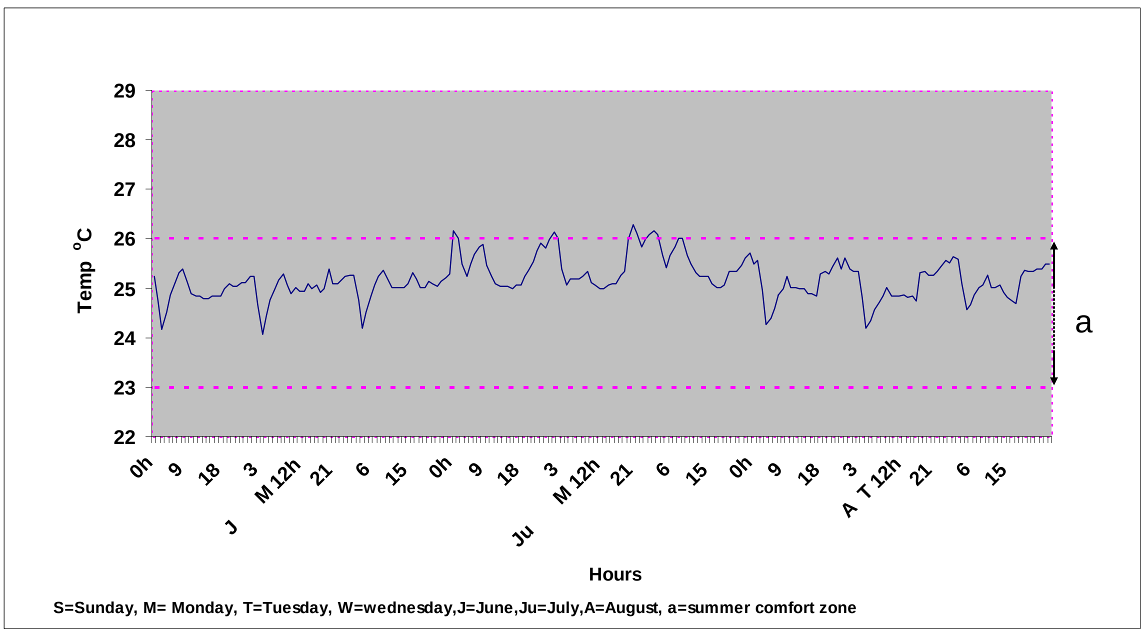


Figure A10: Summer days temperature profile for sports section

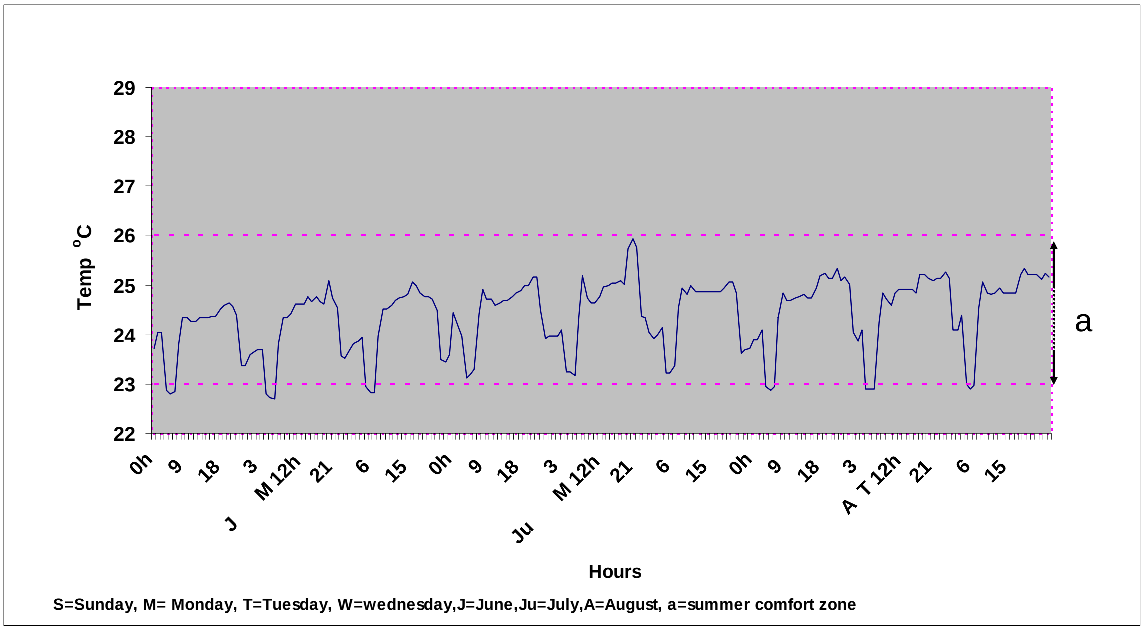


Figure A11: Summer days temperature profile for local news section

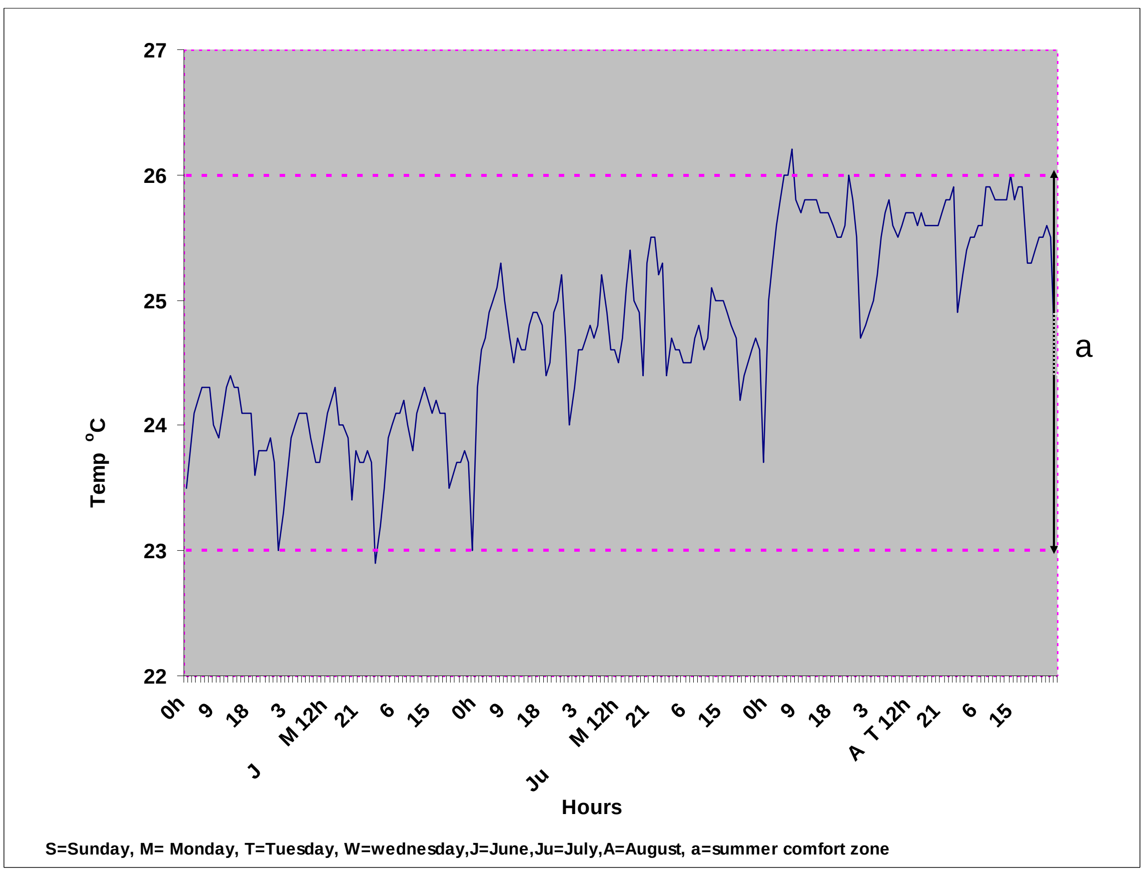


Figure A12: Summer days temperature profile for chief editor's office

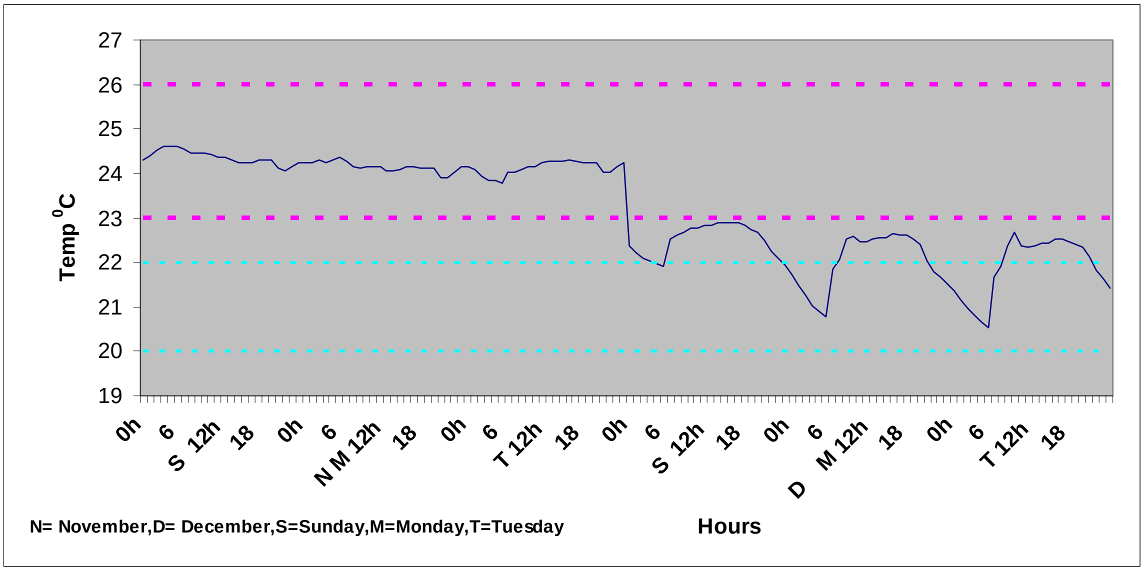


Figure A13: Winter days temperature profile for advertisement section

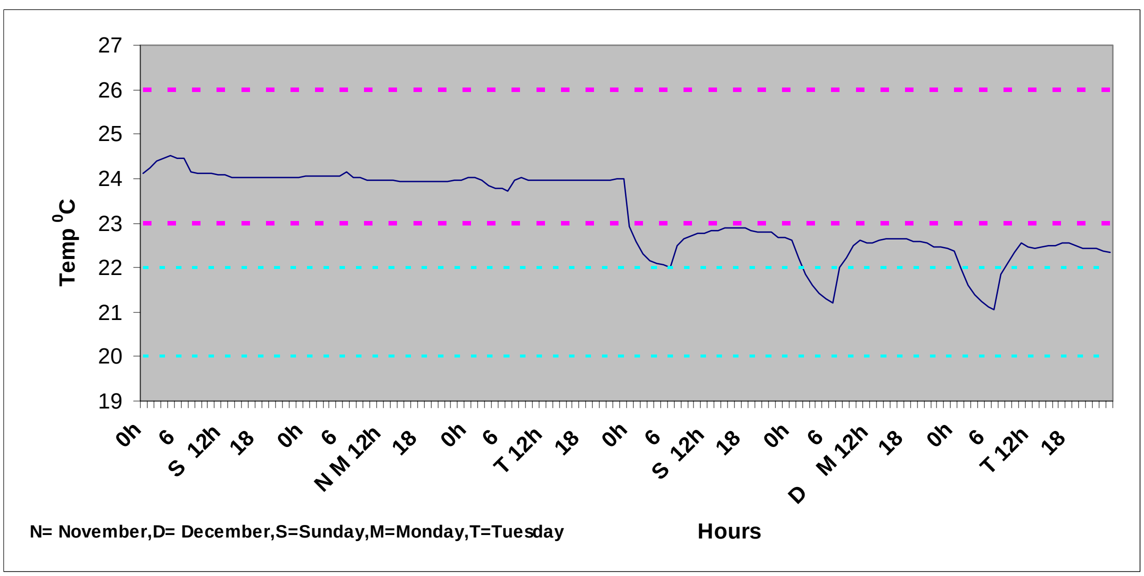


Figure A14: Winter days temperature profile for canteen & training room section

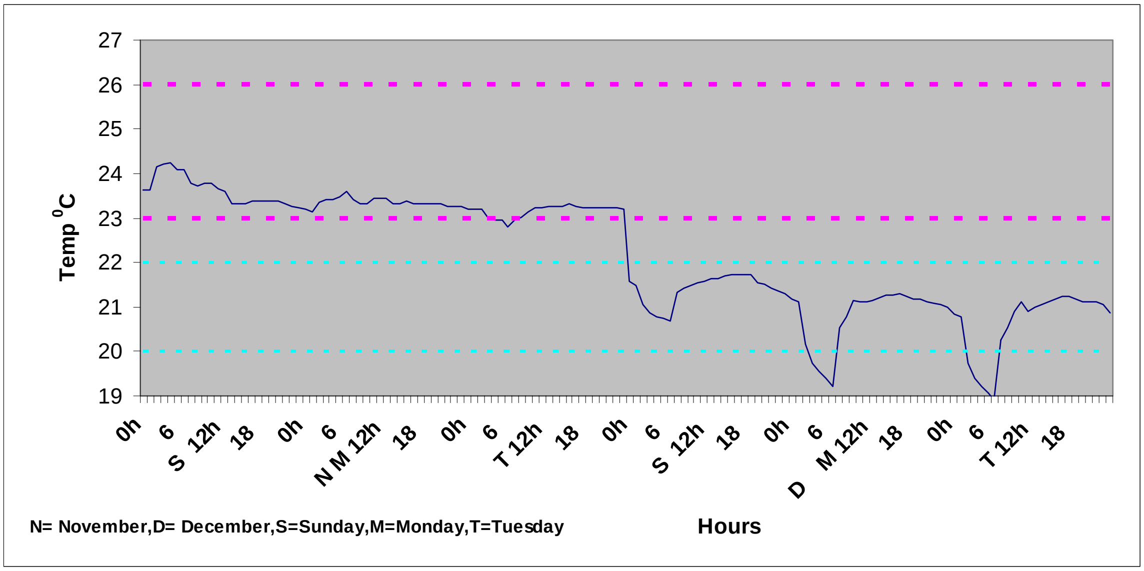


Figure A15: Winter days temperature profile for developing section

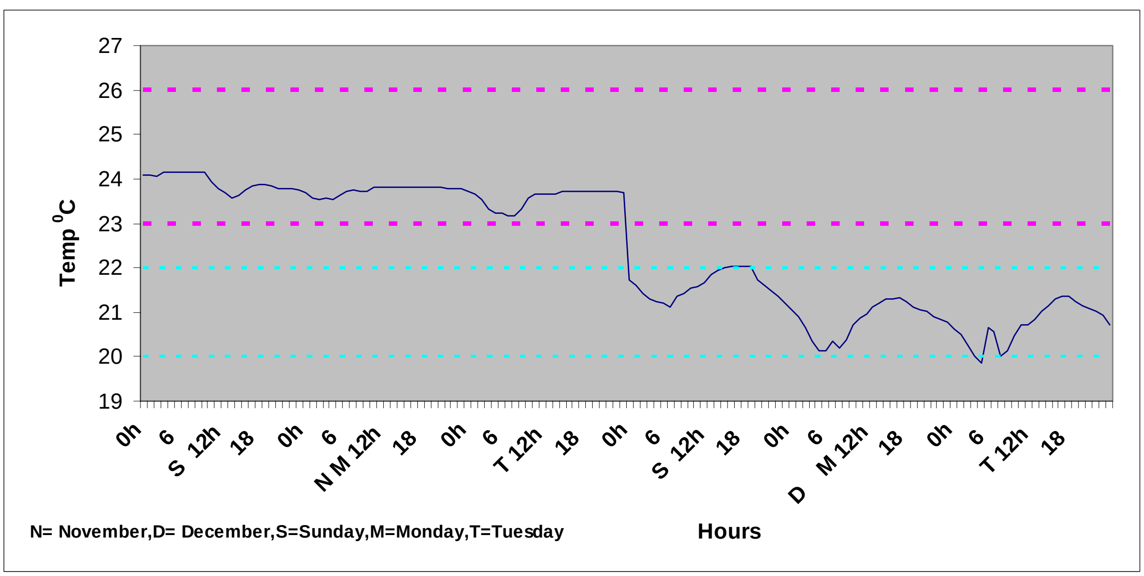


Figure A16: Winter days temperature profile for women section

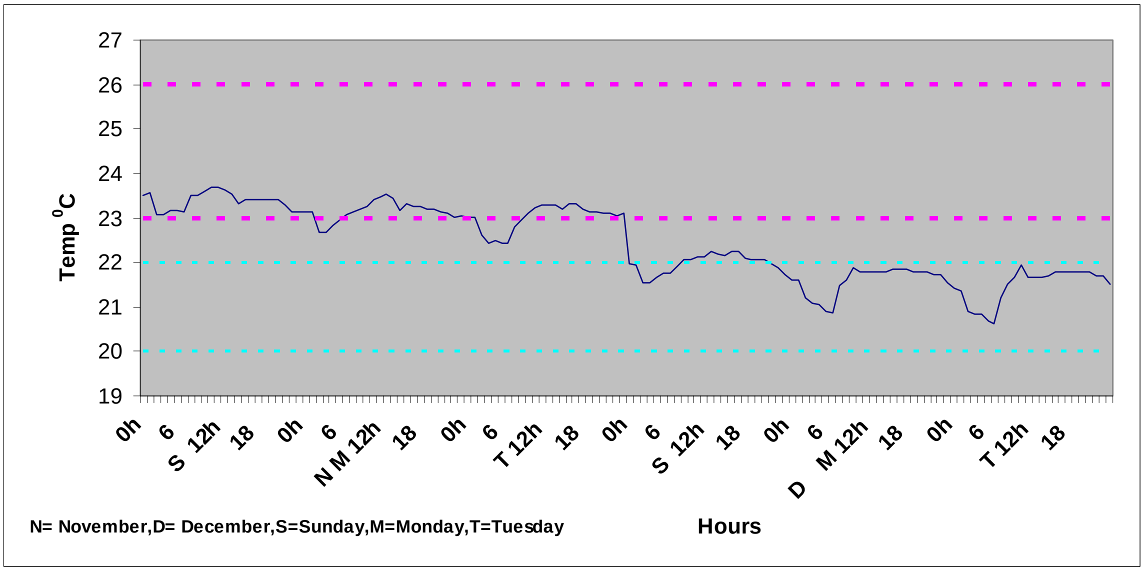


Figure A17: Winter days temperature profile for editing section

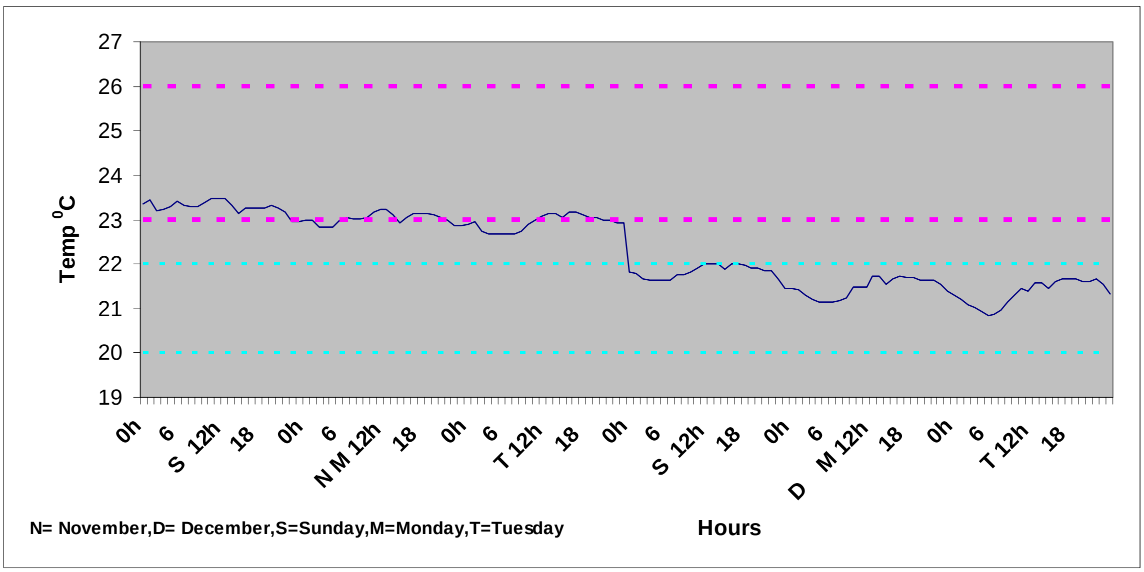


Figure A18: Winter days temperature profile for computer section

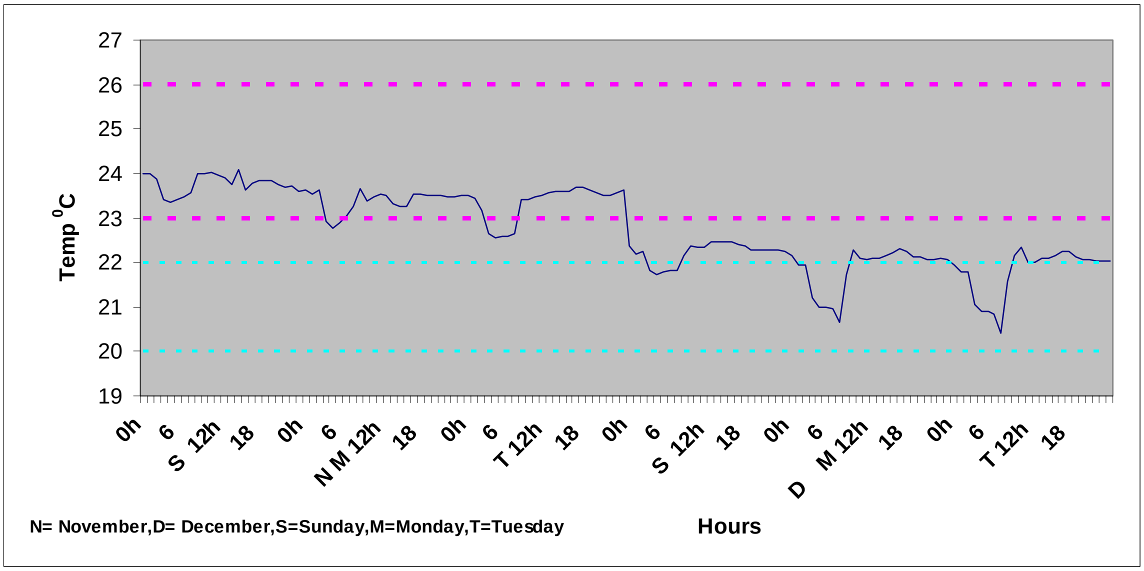


Figure A19: Winter days temperature profile for mosque

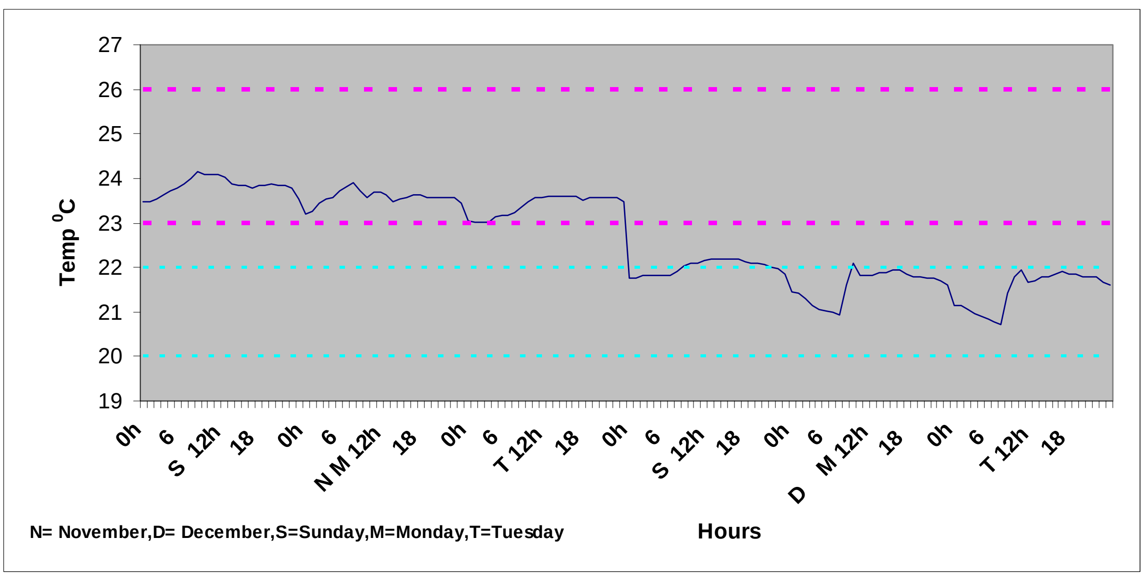


Figure A20: Winter days temperature profile for sports section

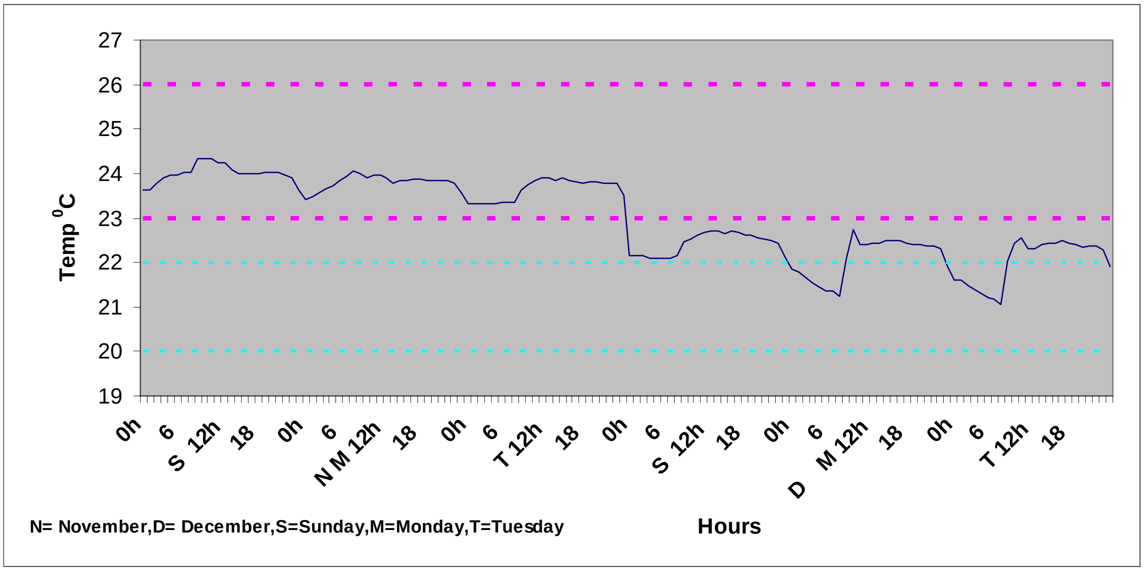


Figure A21: Winter days temperature profile for political section

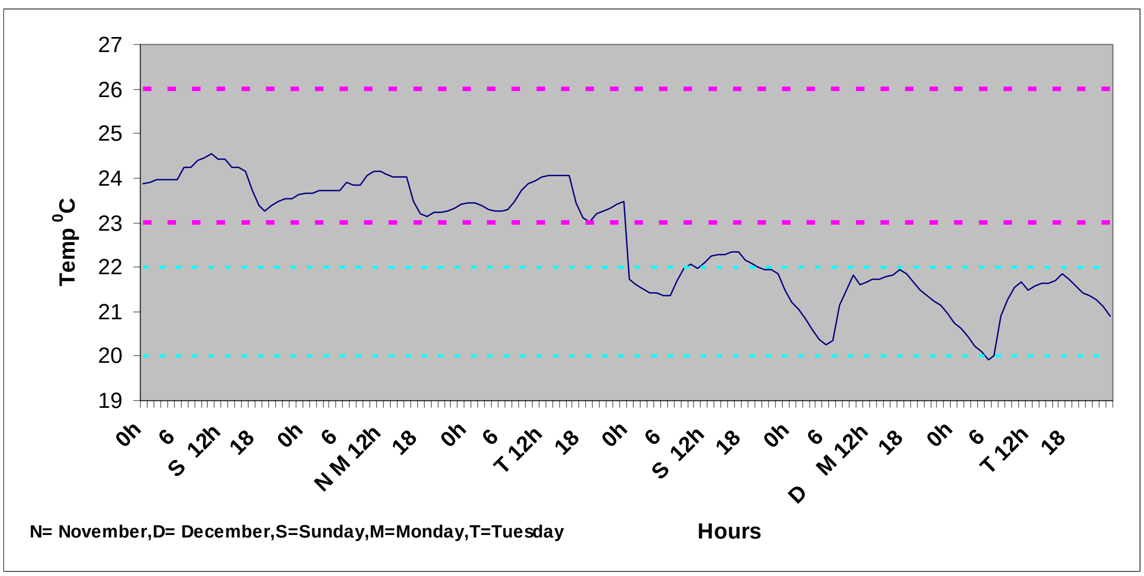


Figure A22: Winter days temperature profile for assistant editor office

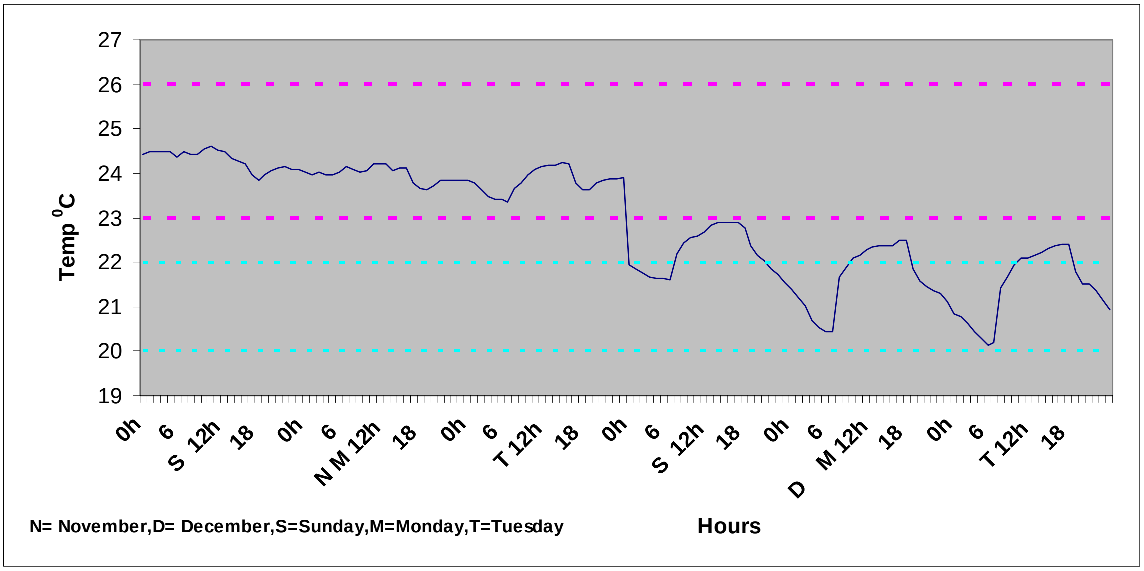


Figure A23: Winter days temperature profile for administration section

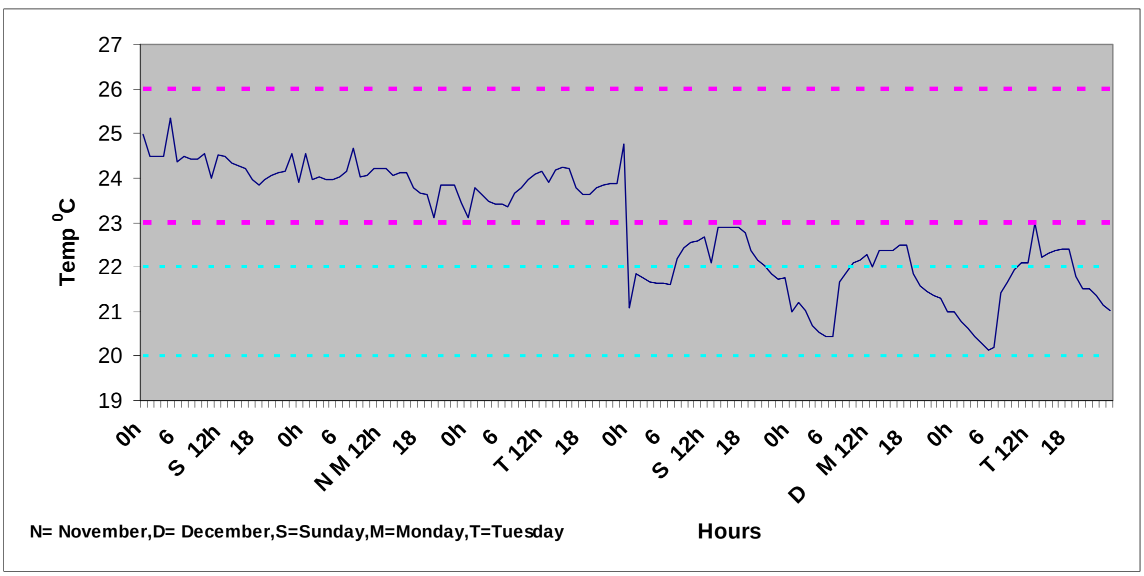


Figure A24: Winter days temperature profile for maintenance section

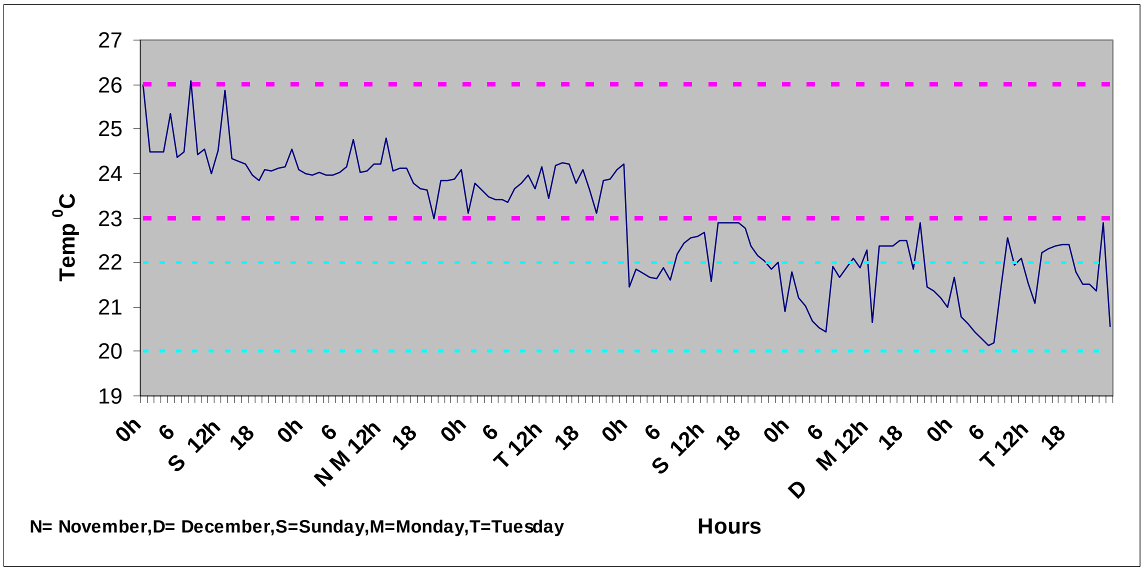


Figure A25: Winter days temperature profile for managing director’s office

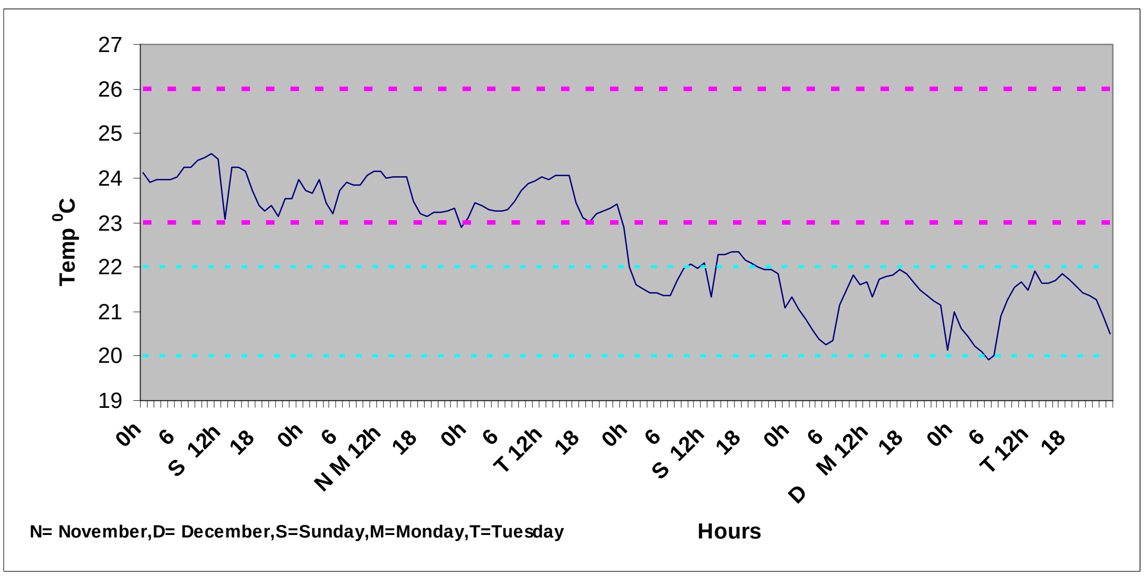


Figure A26: Winter days temperature profile for accounting section

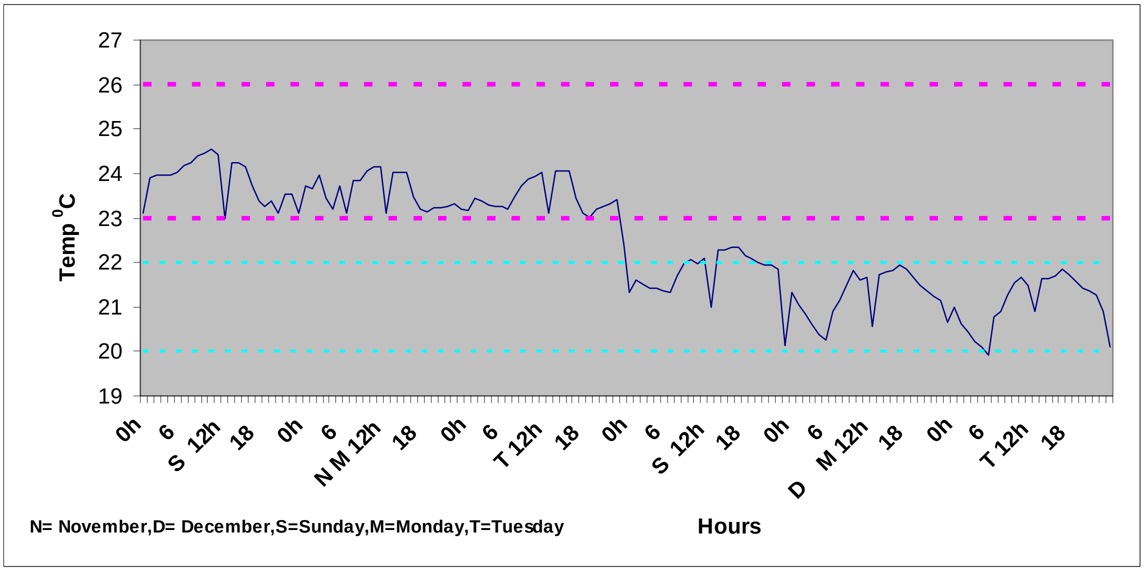


Figure A27: Winter days temperature profile for chief editor section

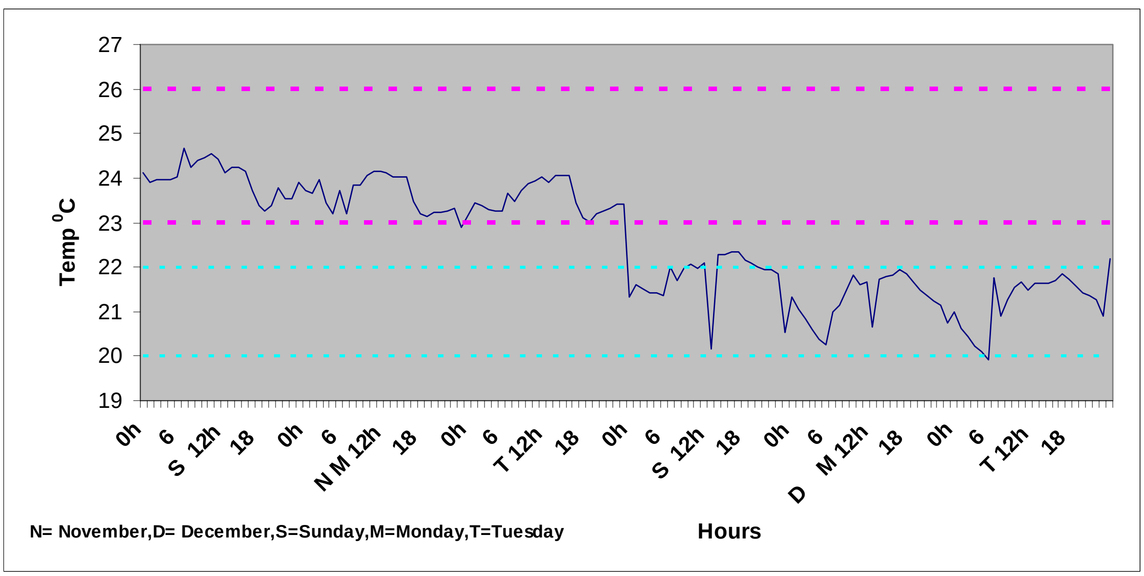


Figure A28: Winter days temperature profile for office section

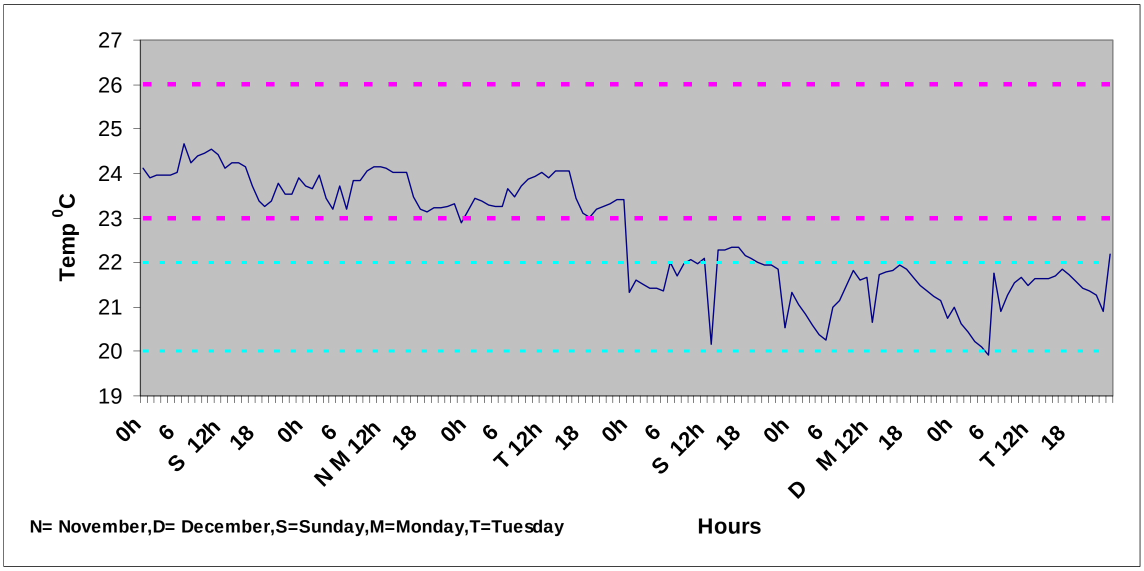


Figure A29: Winter days temperature profile for managing director's office

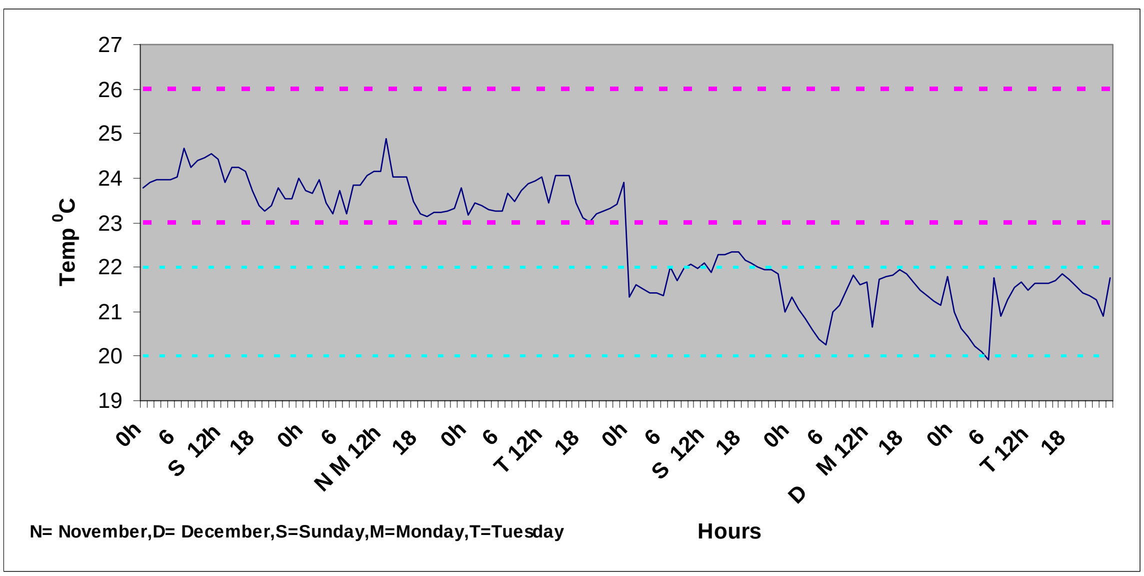


Figure A30: Winter days temperature profile for meeting room

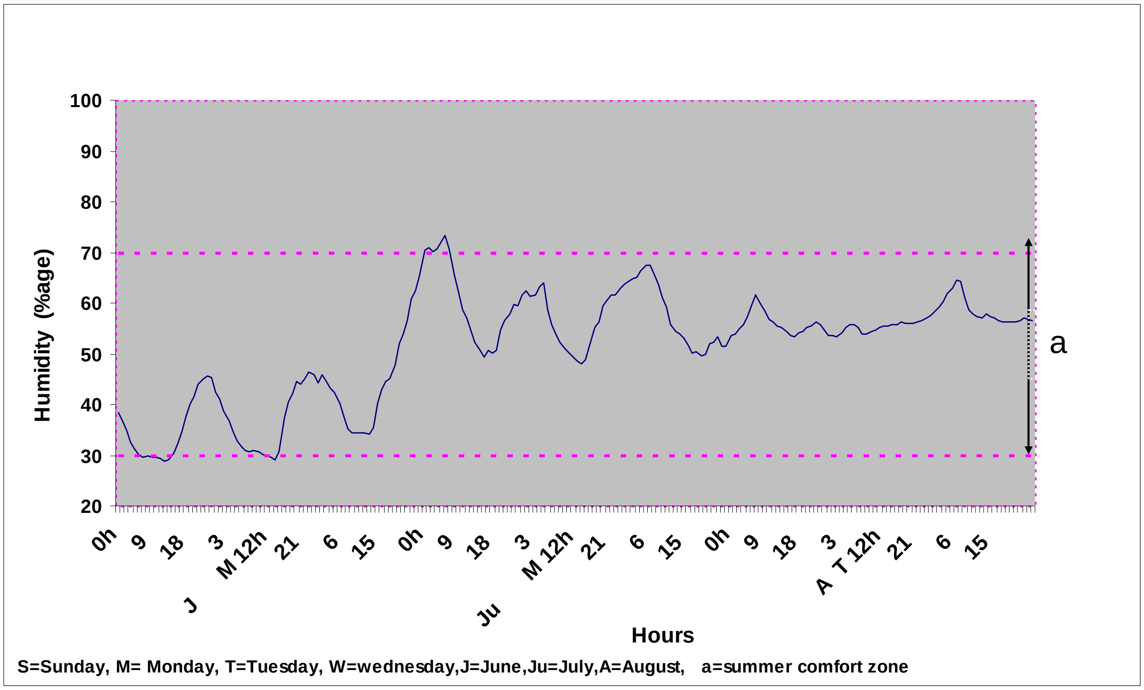


Figure A31: Summer days humidity profile for women section

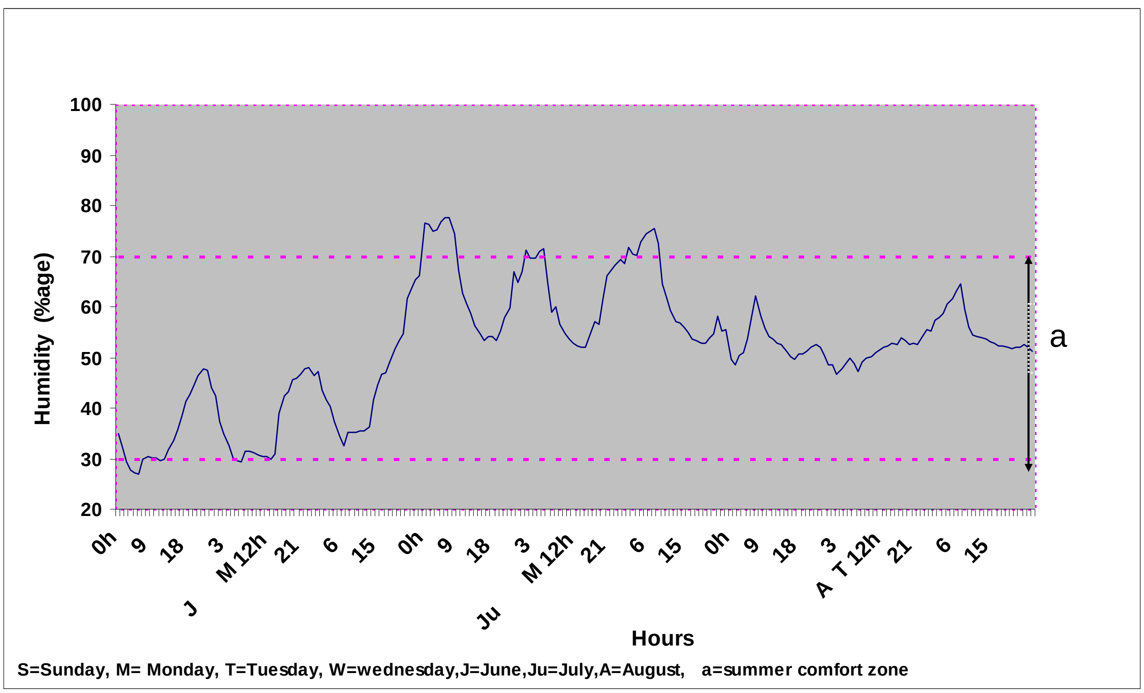


Figure A32: Summer days humidity profile for developing and telephone section

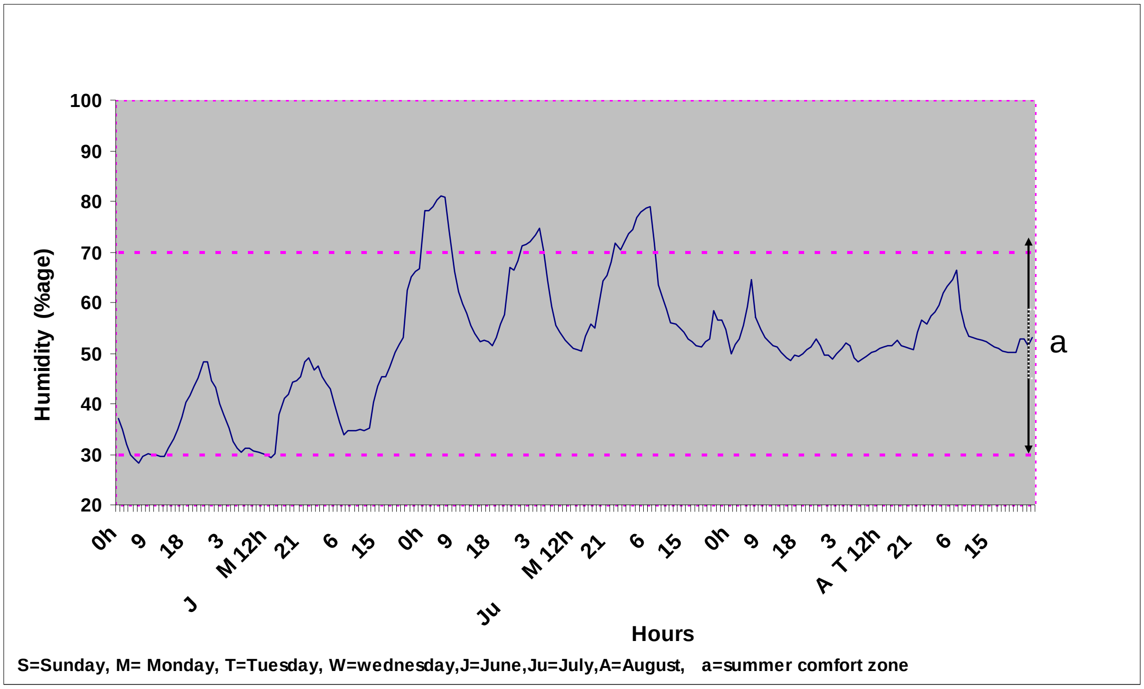


Figure A33: Summer days humidity profile for canteen and training room

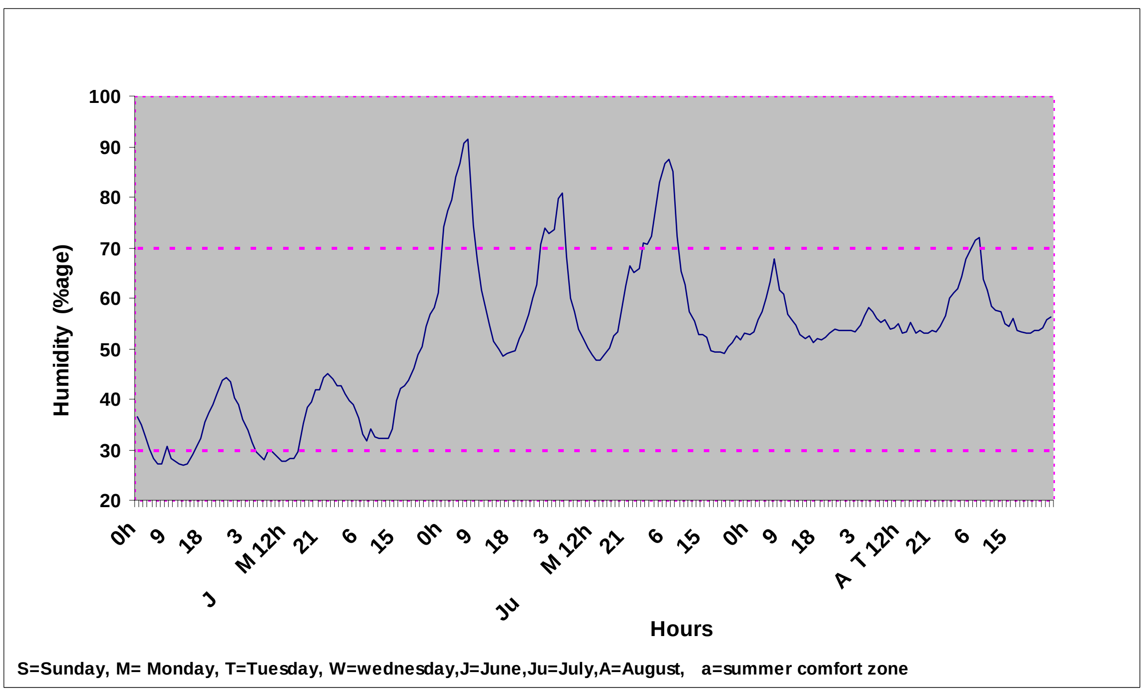


Figure A34: Summer days humidity profile for mosque

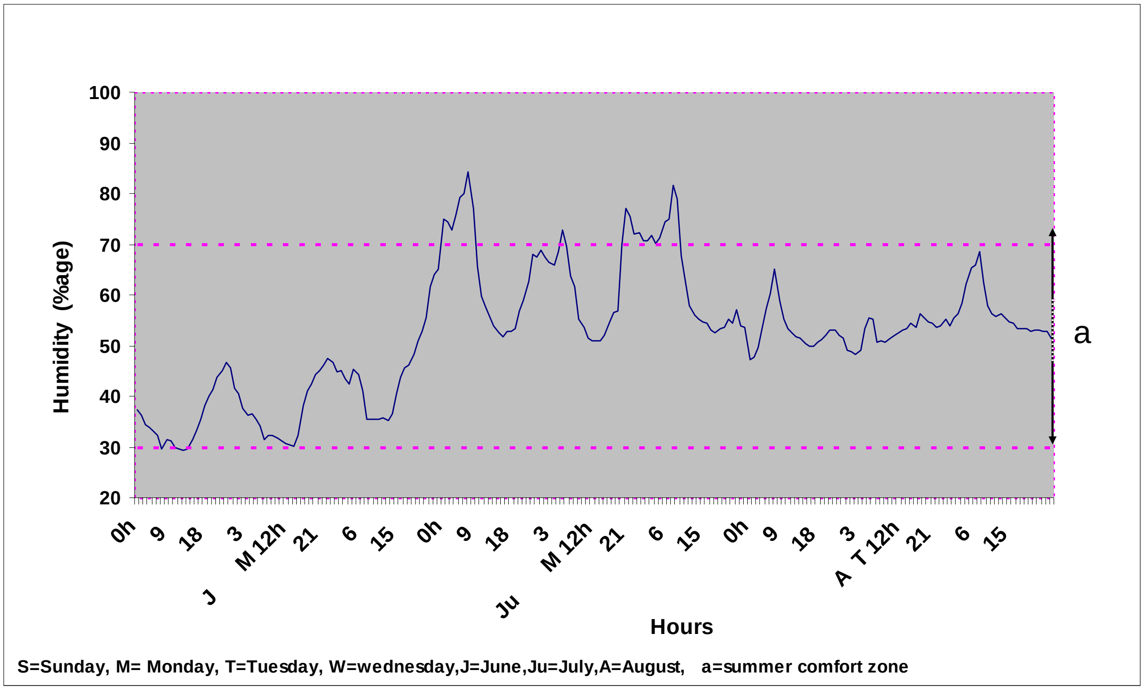


Figure A35: Summer days humidity profile for computer section

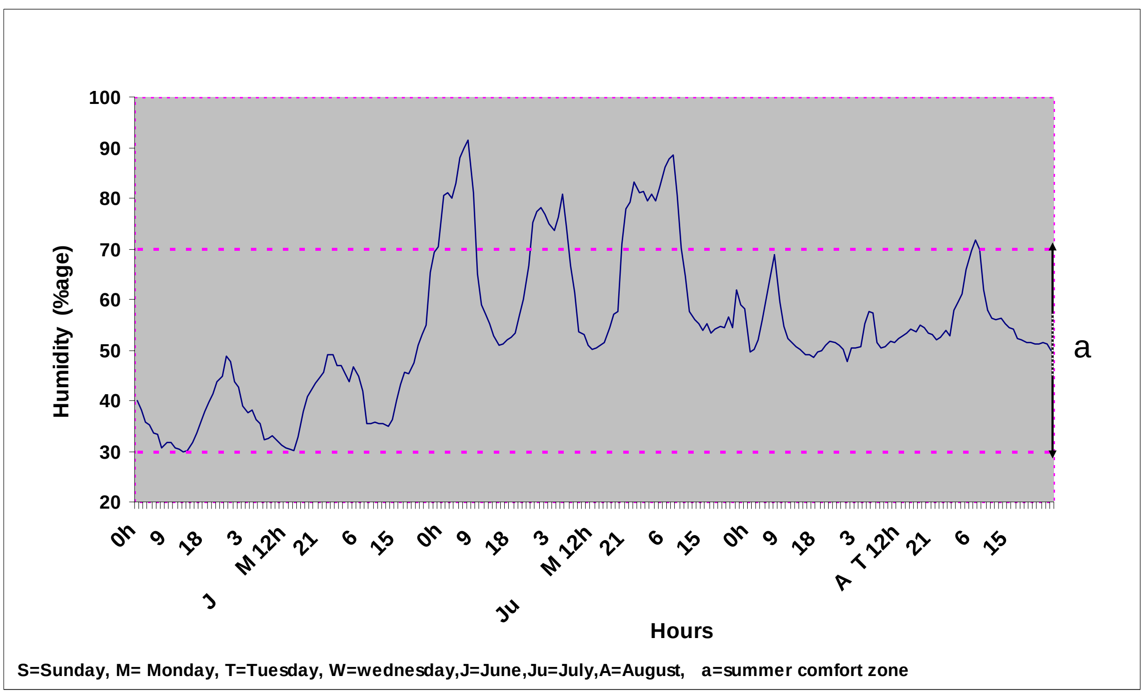


Figure A36: Summer days humidity profile for editing section

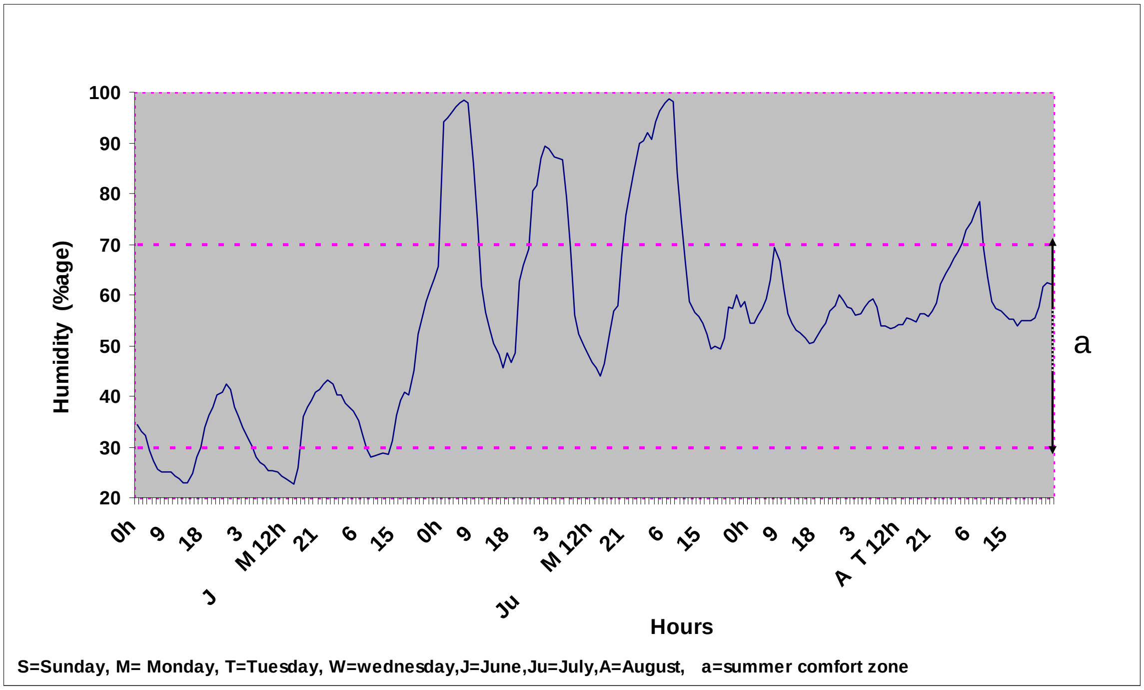


Figure A37: Summer days humidity profile for accounting section

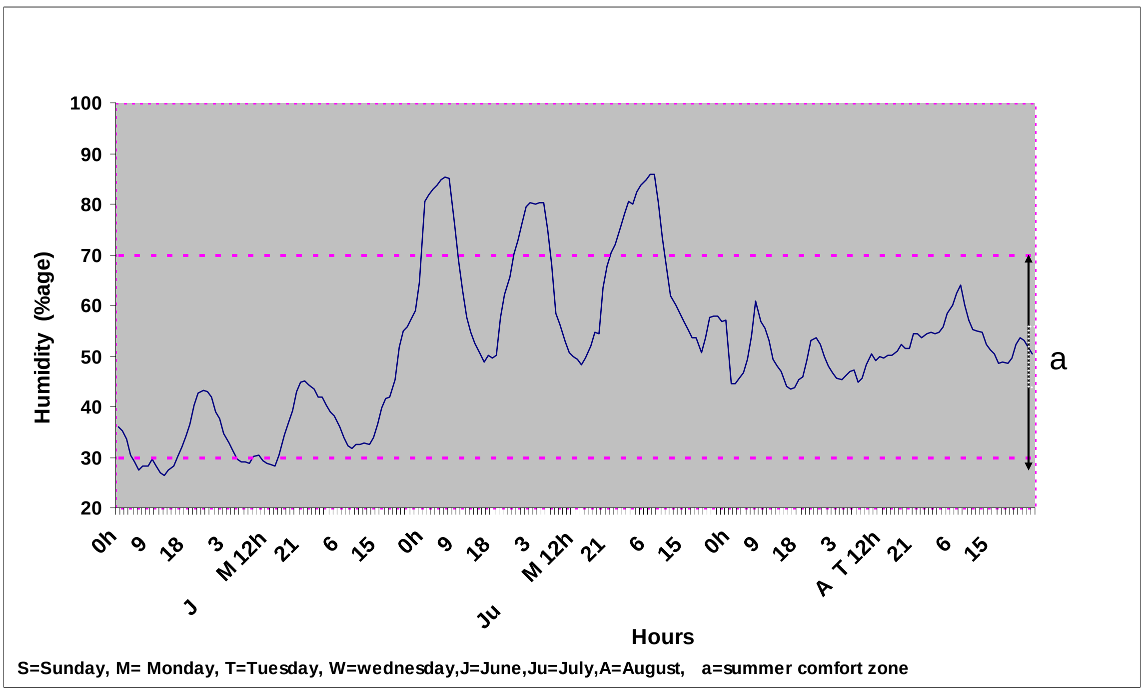


Figure A38: Summer days humidity profile for assistant managing director's office

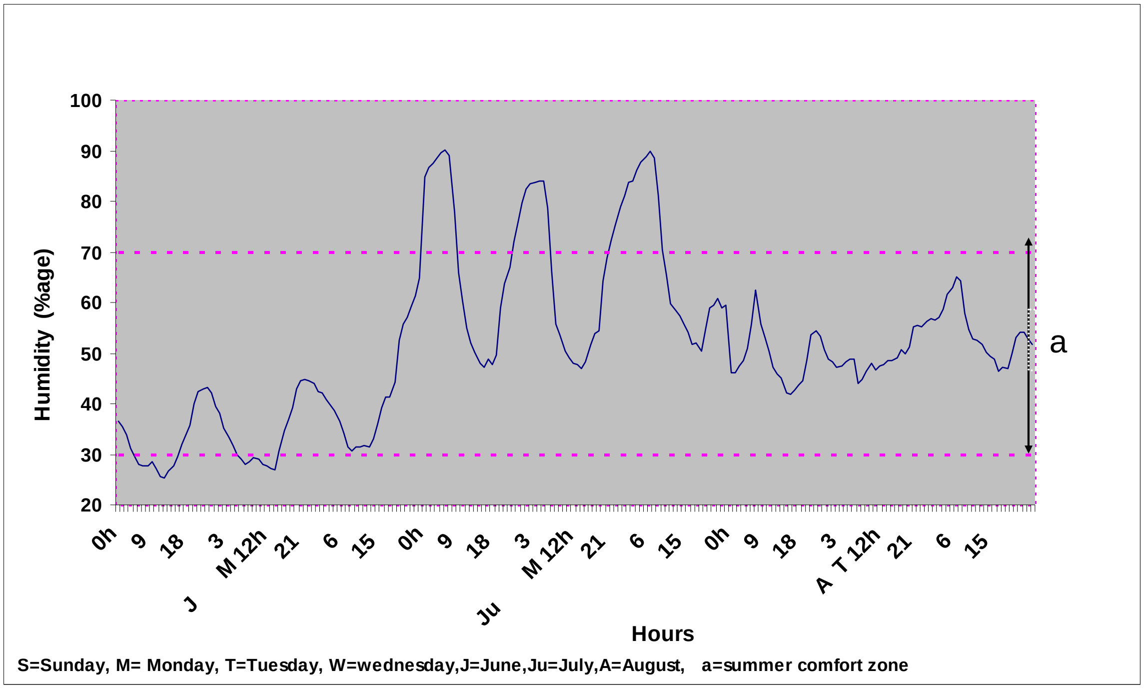


Figure A39: Summer days humidity profile for maintenance section

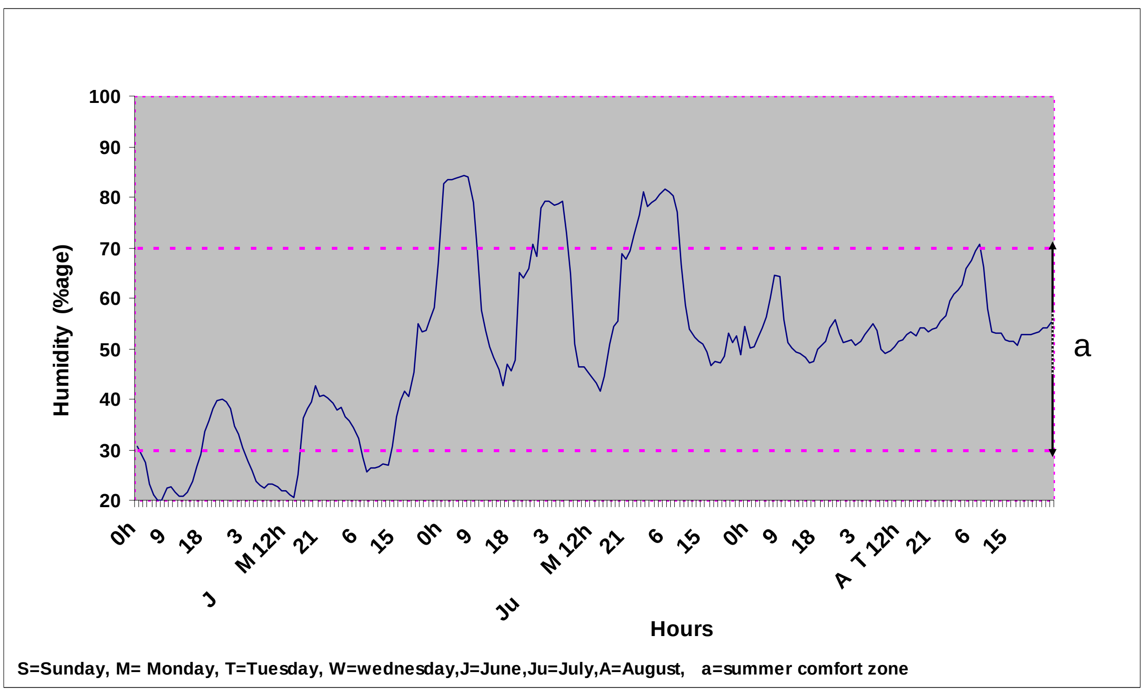


Figure A40: Summer days humidity profile for meeting room

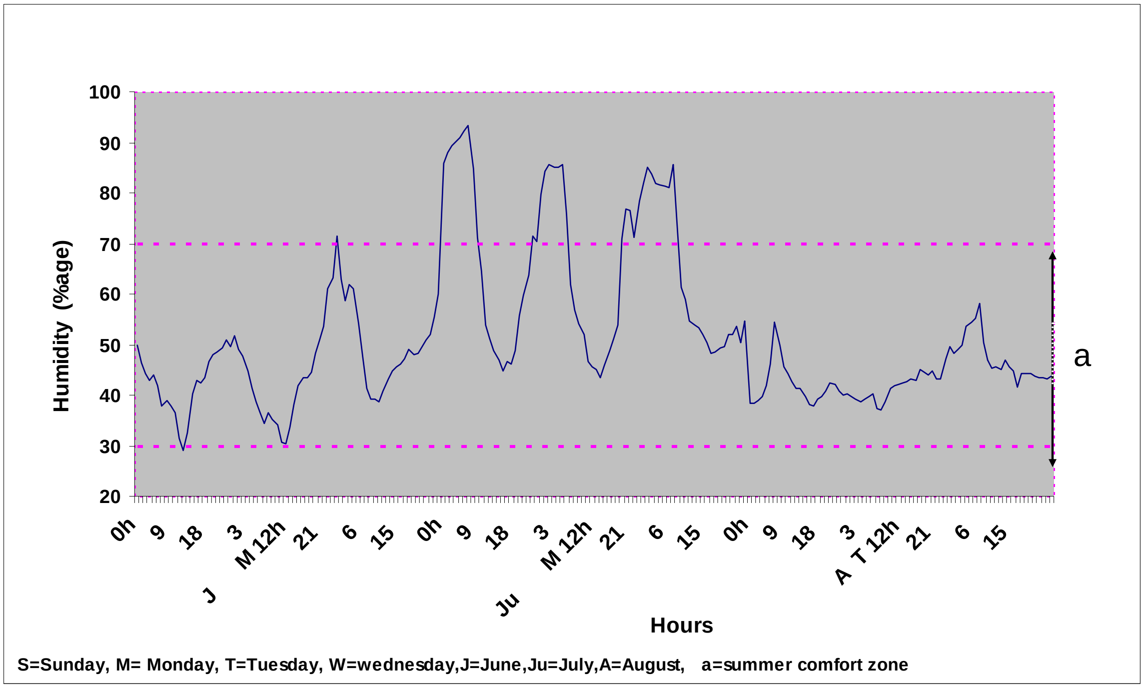


Figure A41: Summer days humidity profile for managing director's office

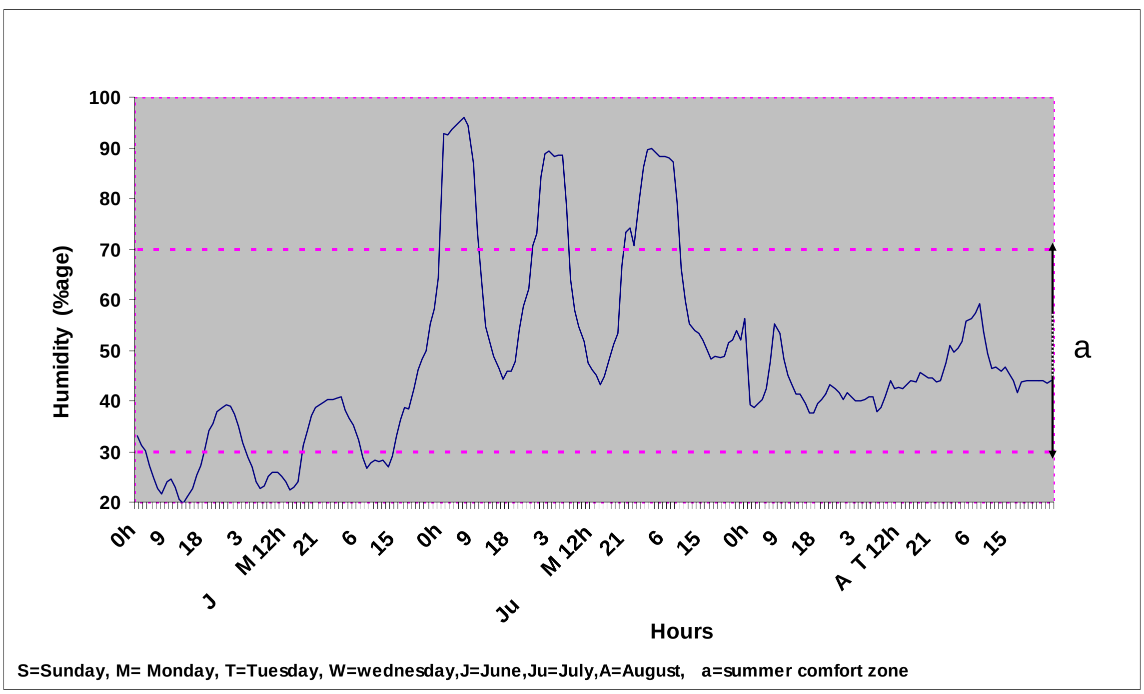


Figure A42: Summer days humidity profile for office section

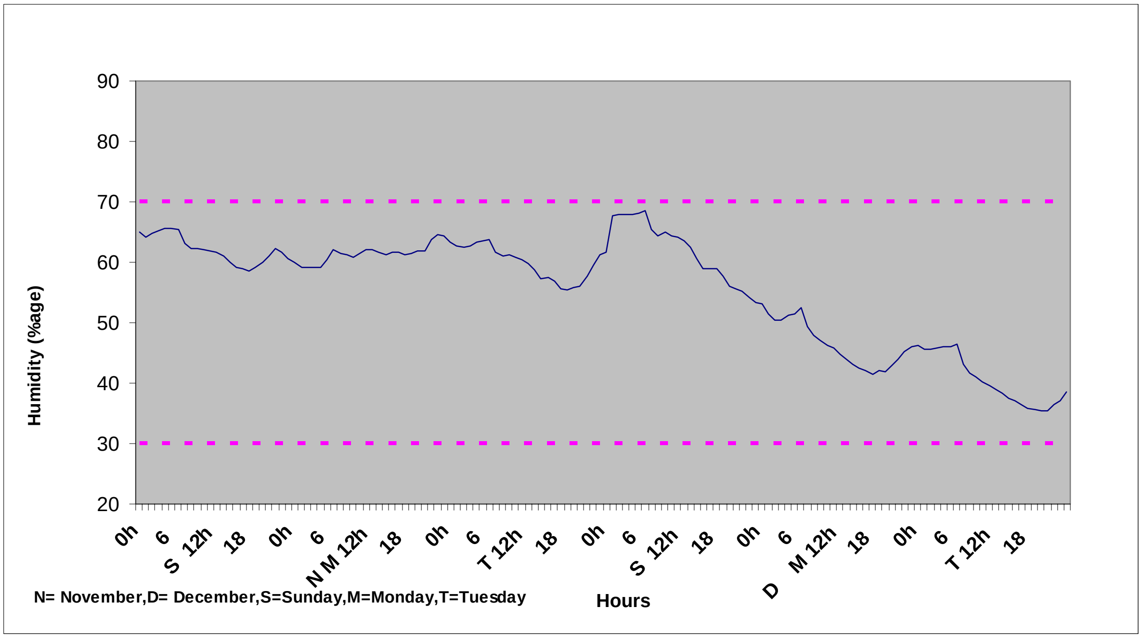


Figure A43: Winter days humidity profile for advertisement section

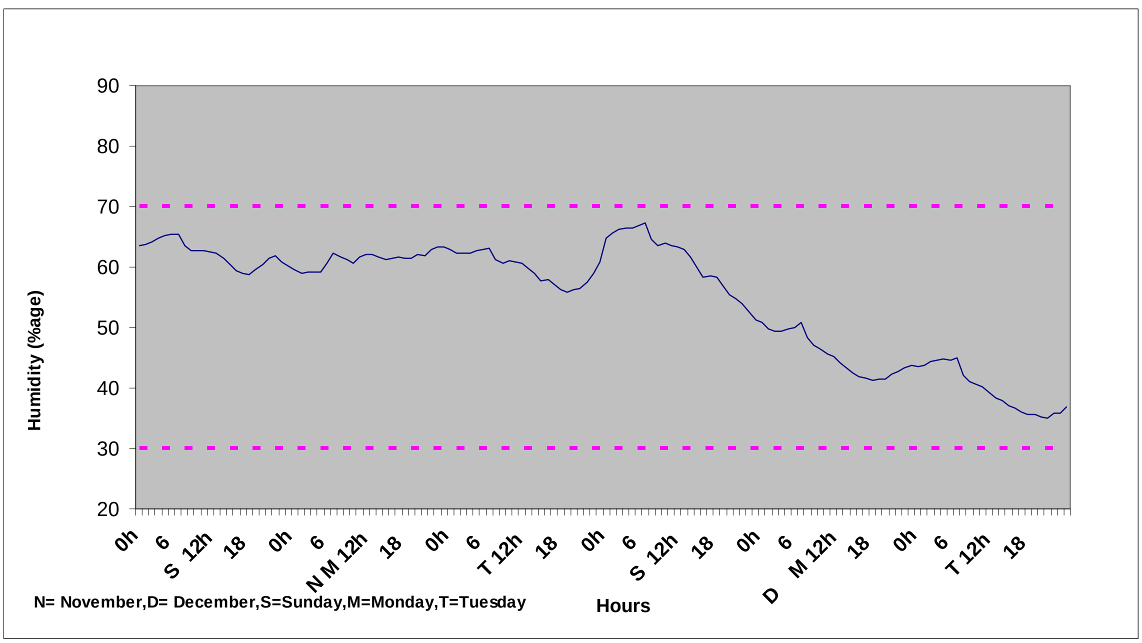


Figure A44: Winter days humidity profile for canteen & training room

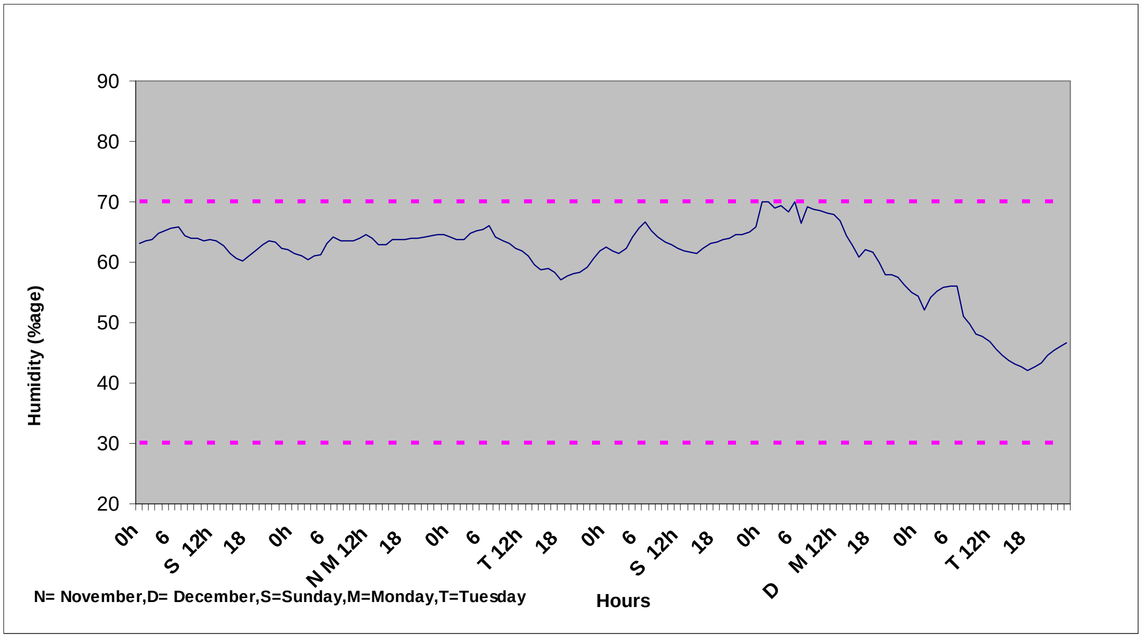


Figure A45: Winter days humidity profile for developing section

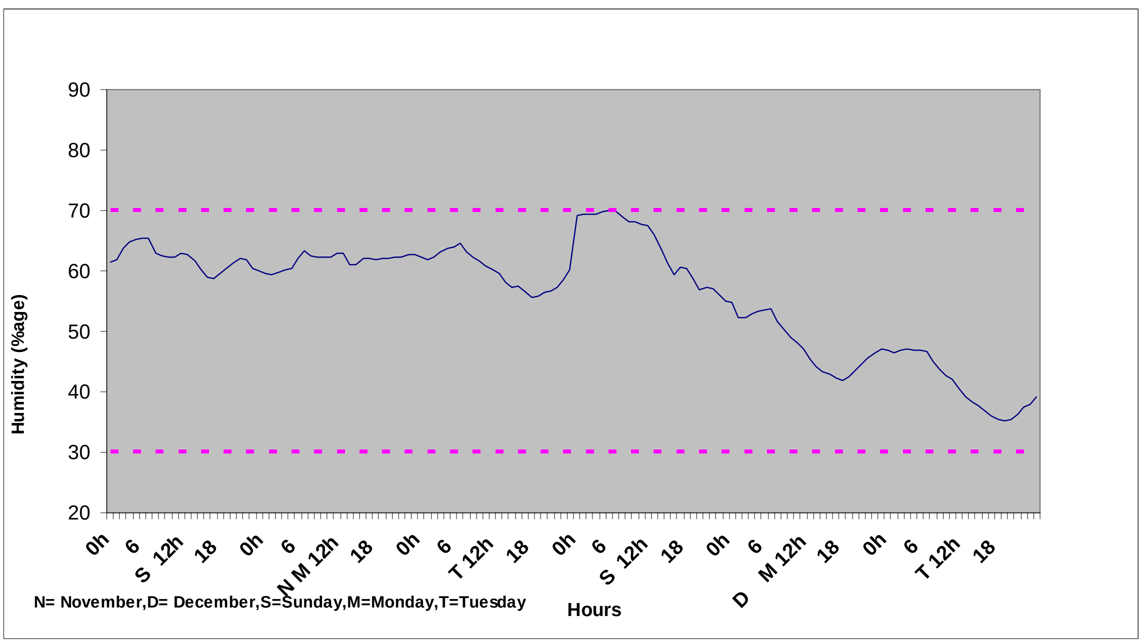


Figure A46: Winter days humidity profile for women section

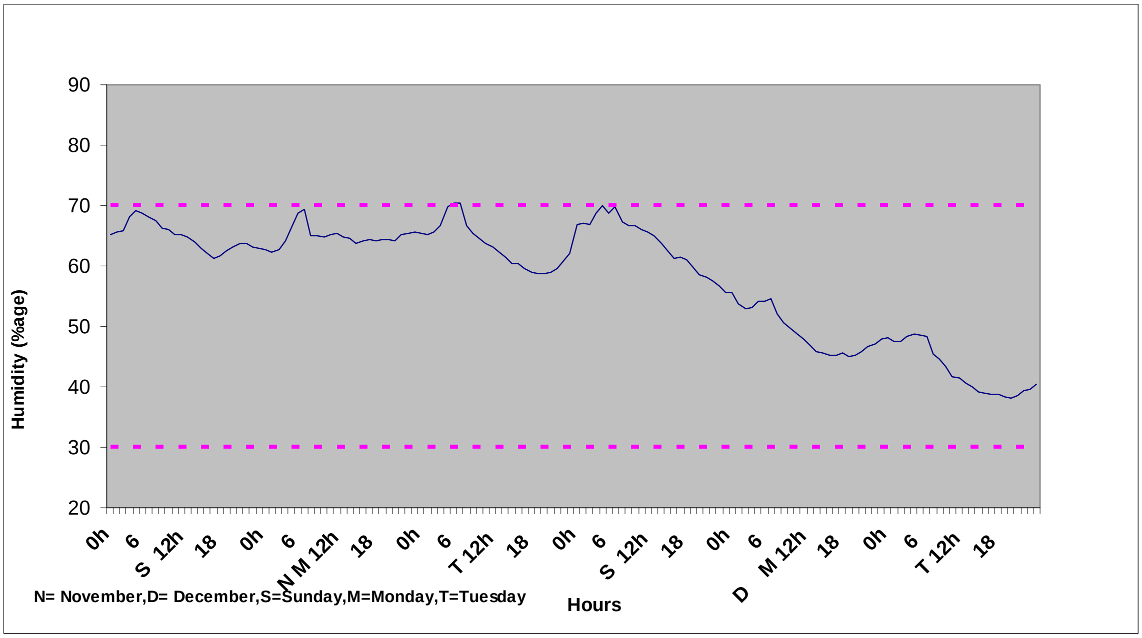


Figure A47: Winter days humidity profile for design & publication section

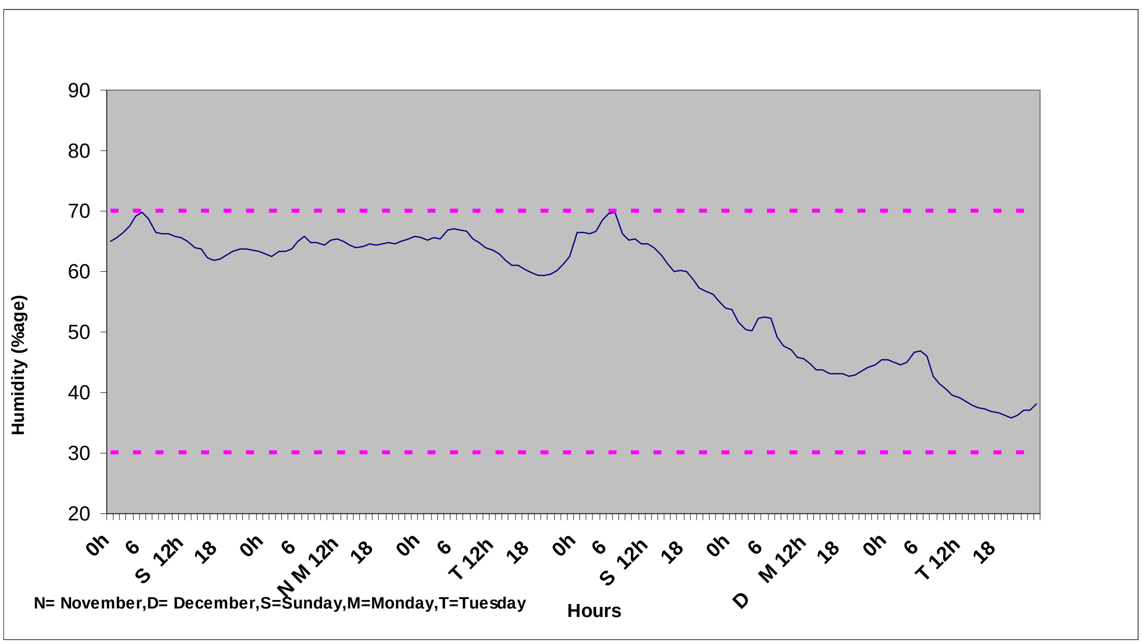


Figure A48: Winter days humidity profile for editing section

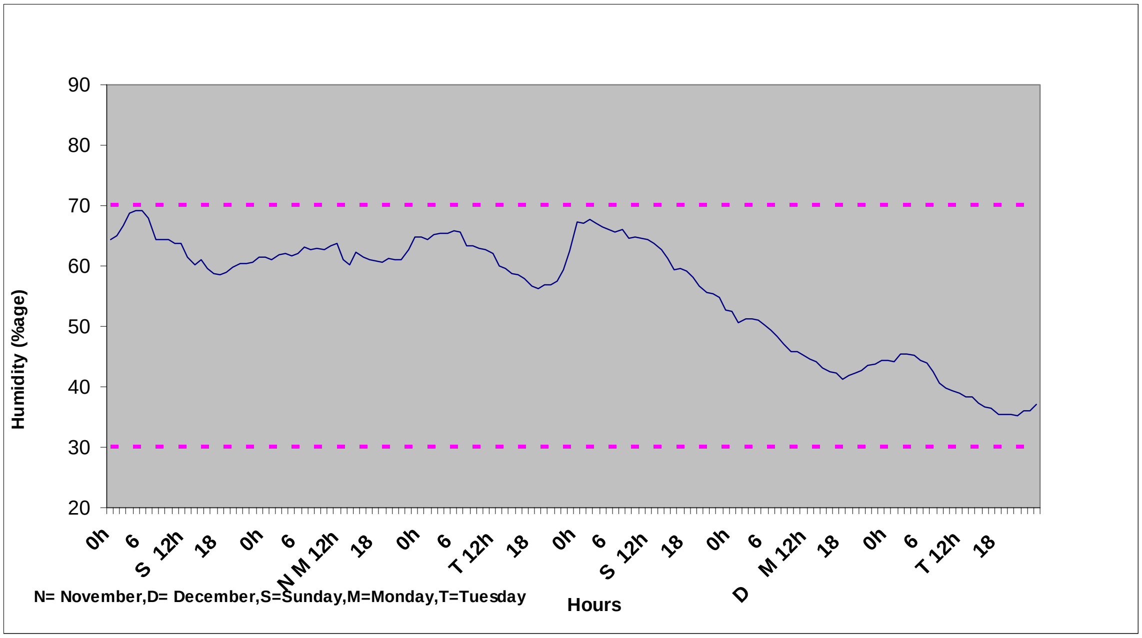


Figure A49: Winter days humidity profile for computer section

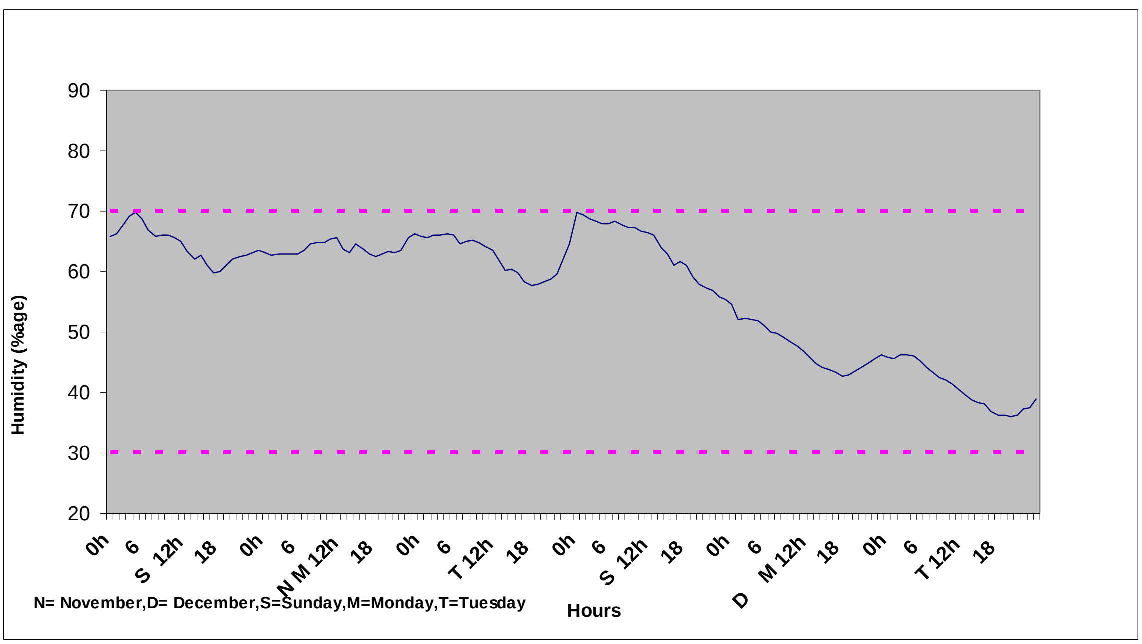


Figure A50: Winter days humidity profile for mosque

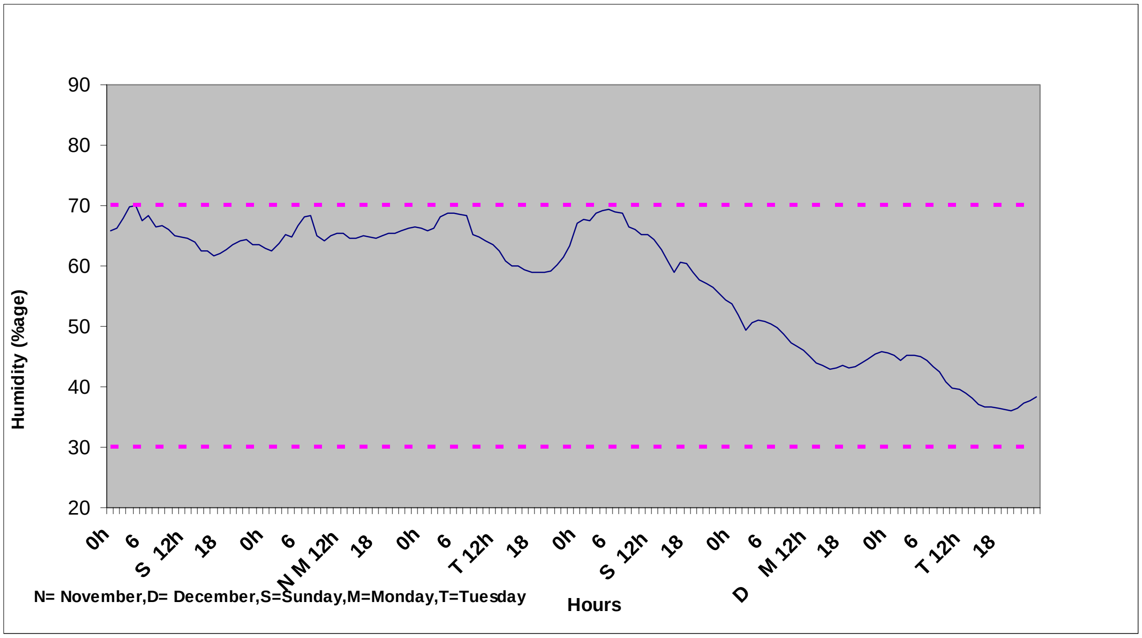


Figure A51: Winter days humidity profile for local news section

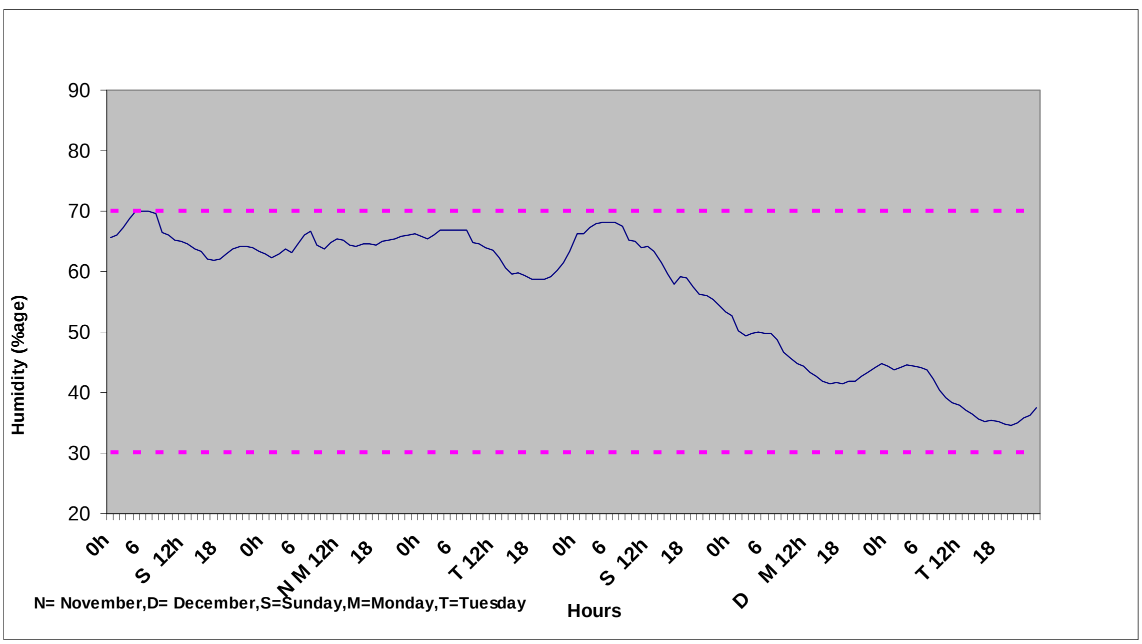


Figure A52: Winter days humidity profile for sports section

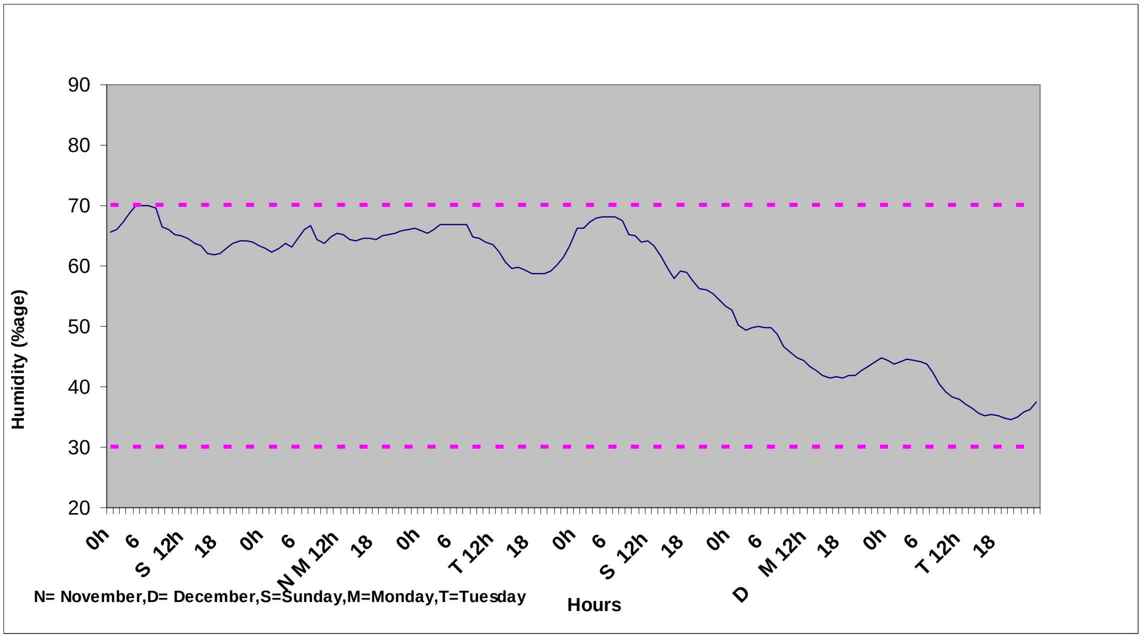


Figure A53: Winter days humidity profile for political section

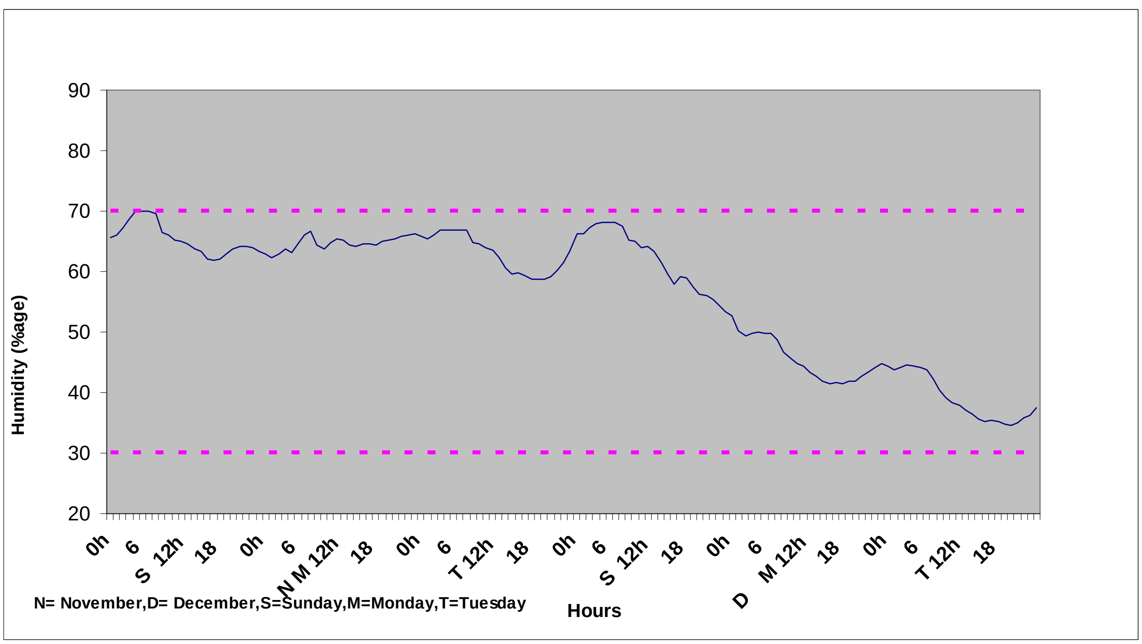


Figure A54: Winter days humidity profile for assistant editor office

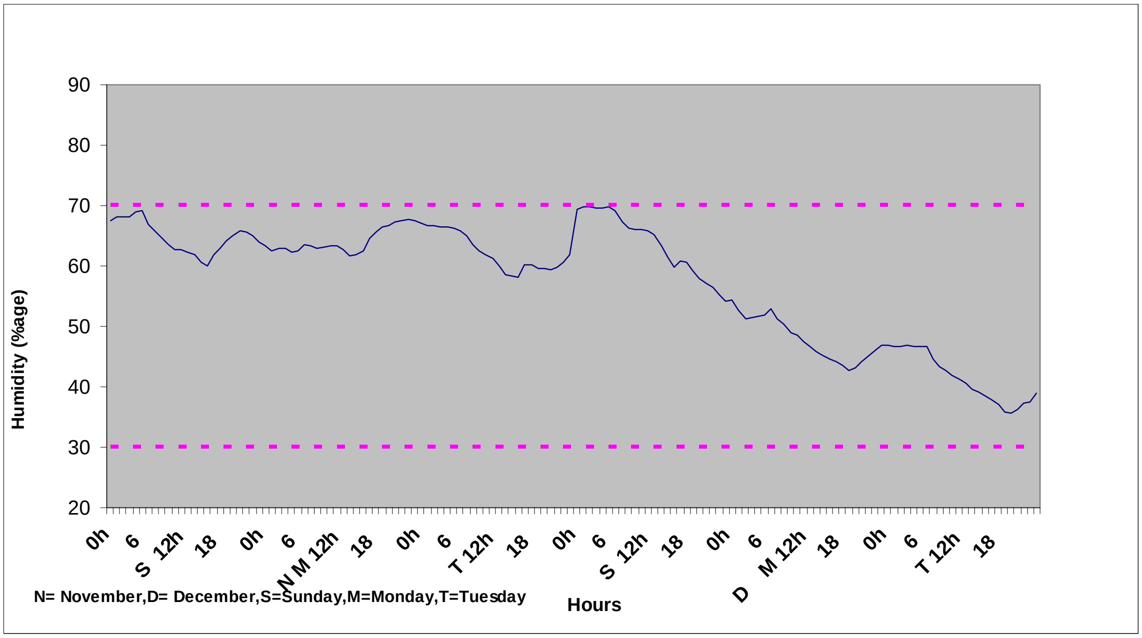


Figure A55: Winter days humidity profile for administration section

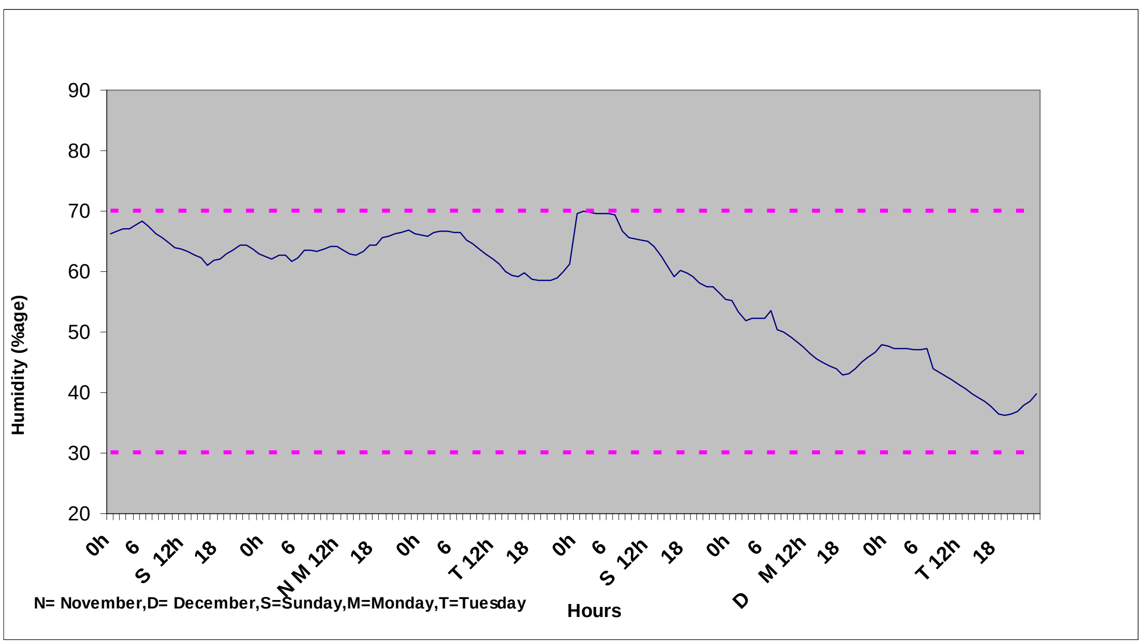


Figure A56: Winter days humidity profile for maintenance section

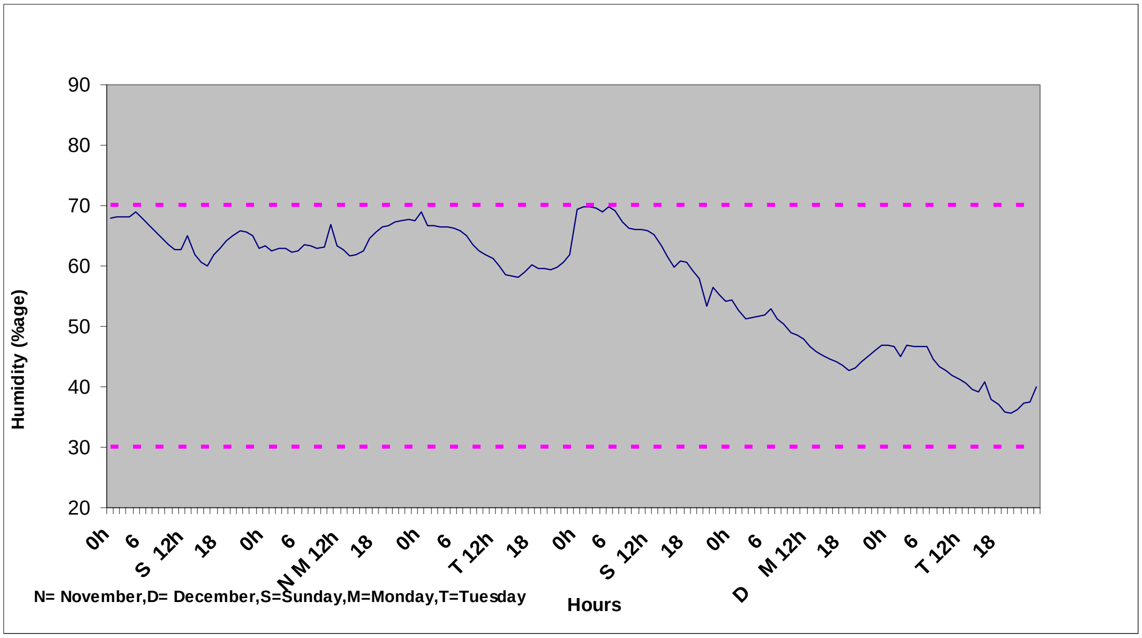


Figure A57: Winter days humidity profile for managing director's office

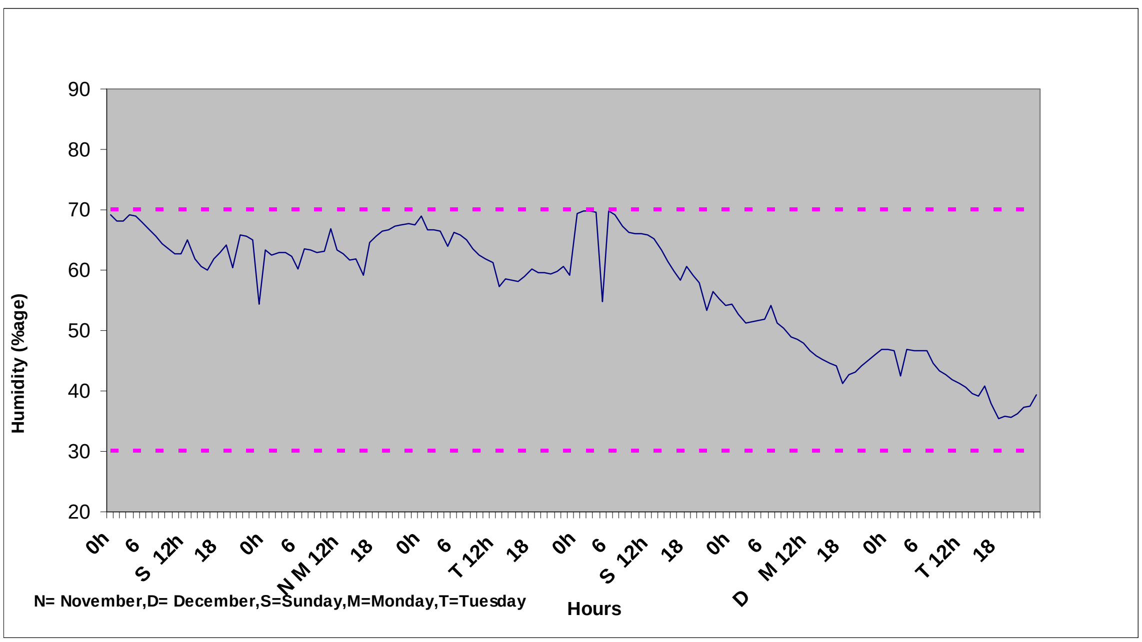


Figure A58: Winter days humidity profile for accounting section

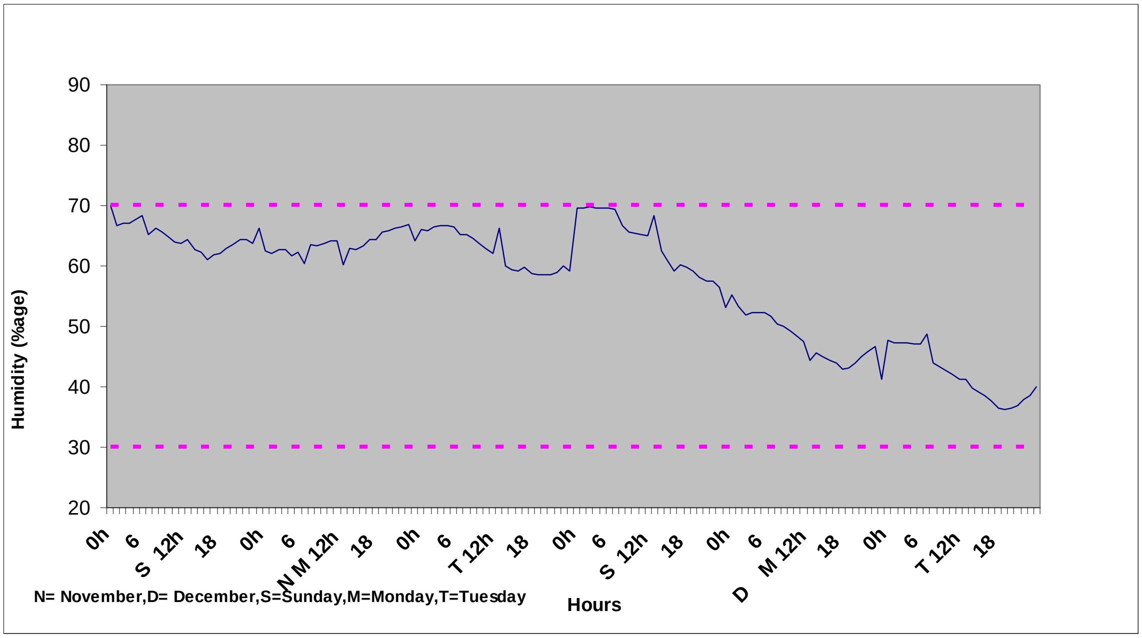


Figure A59: Winter days humidity profile for chief editor's office

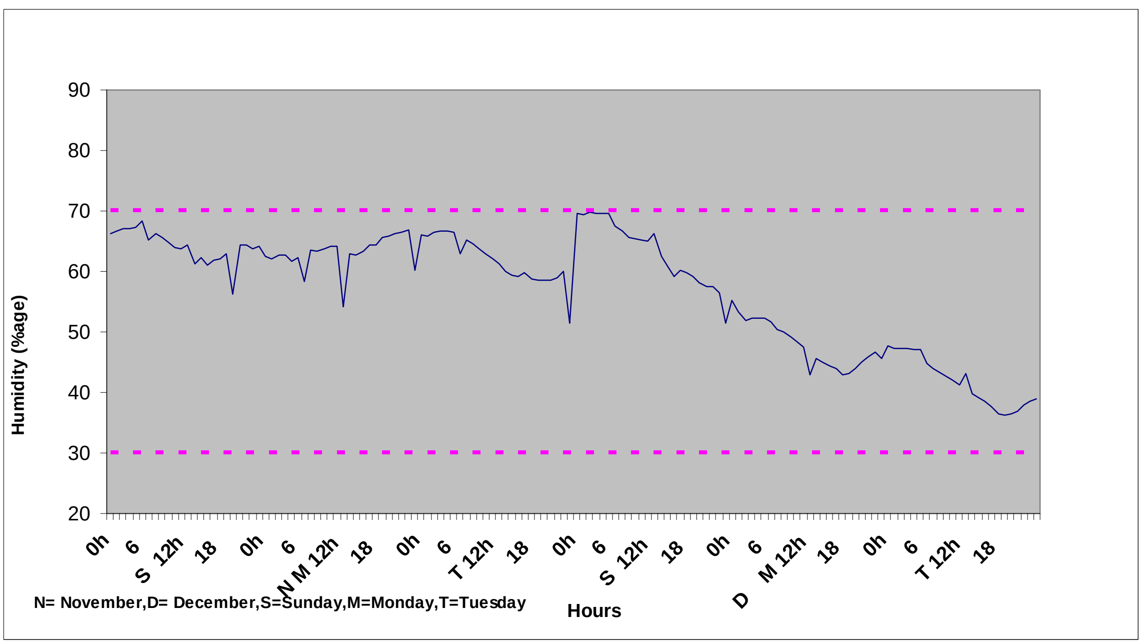


Figure A60: Winter days humidity profile for office section

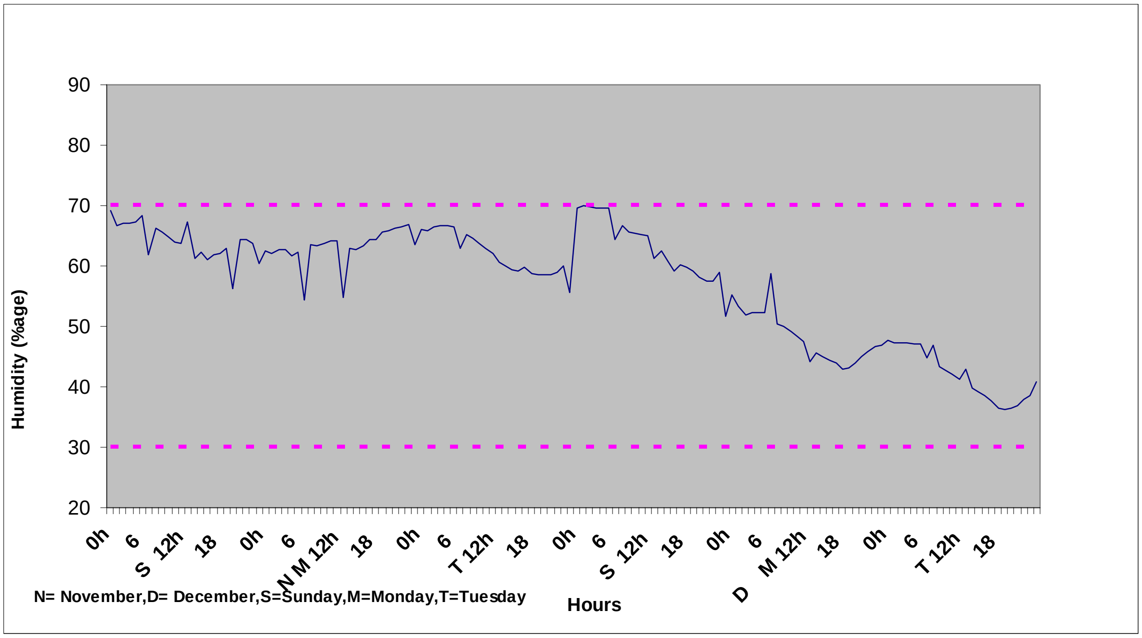


Figure A61: Winter days humidity profile for managing director's office

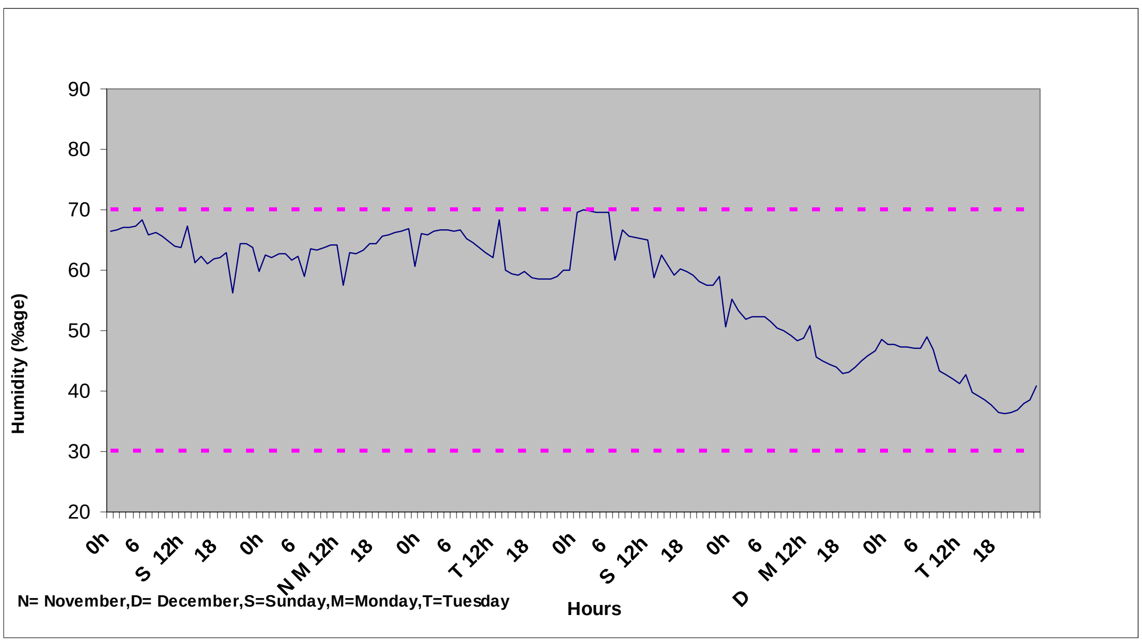
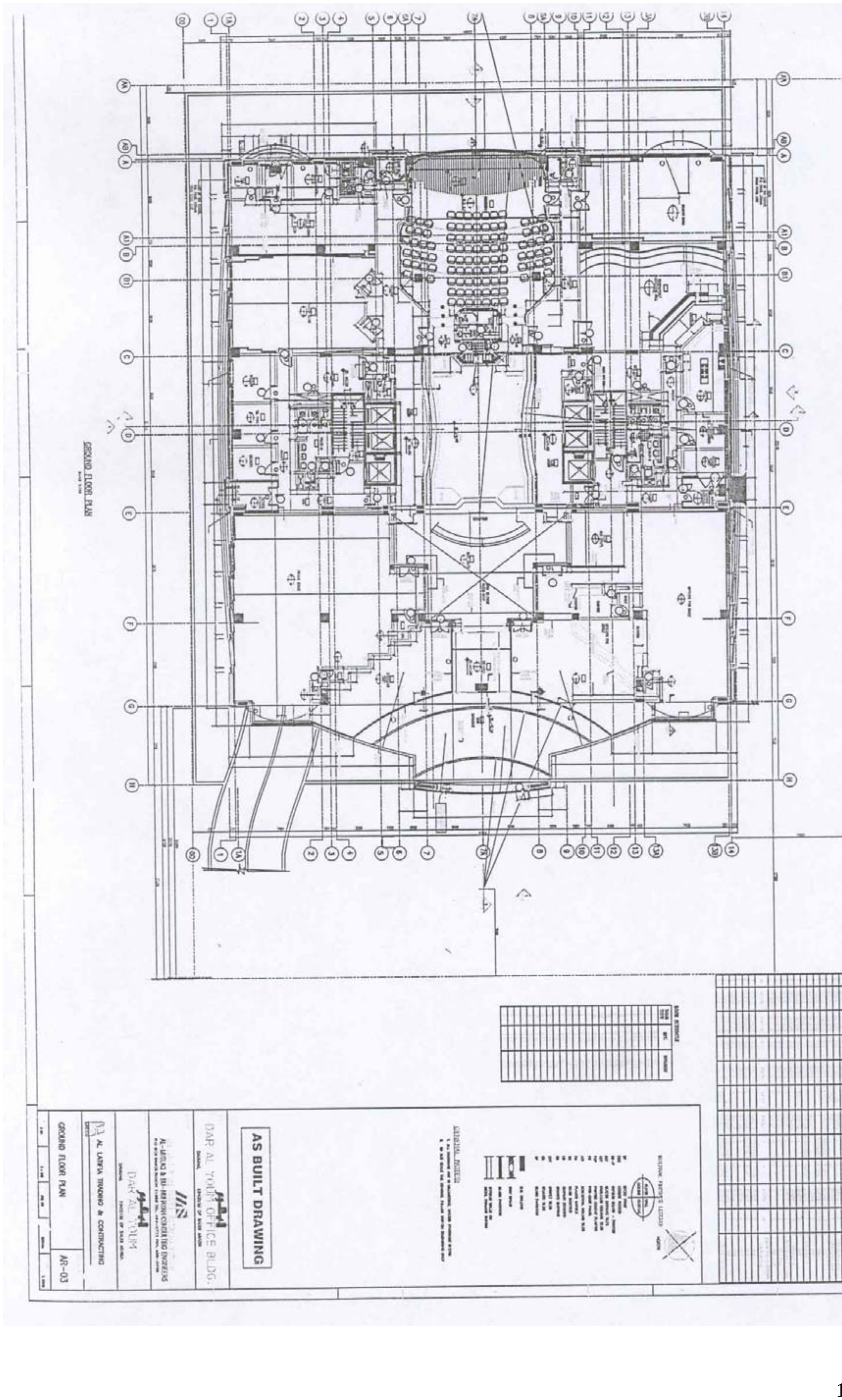
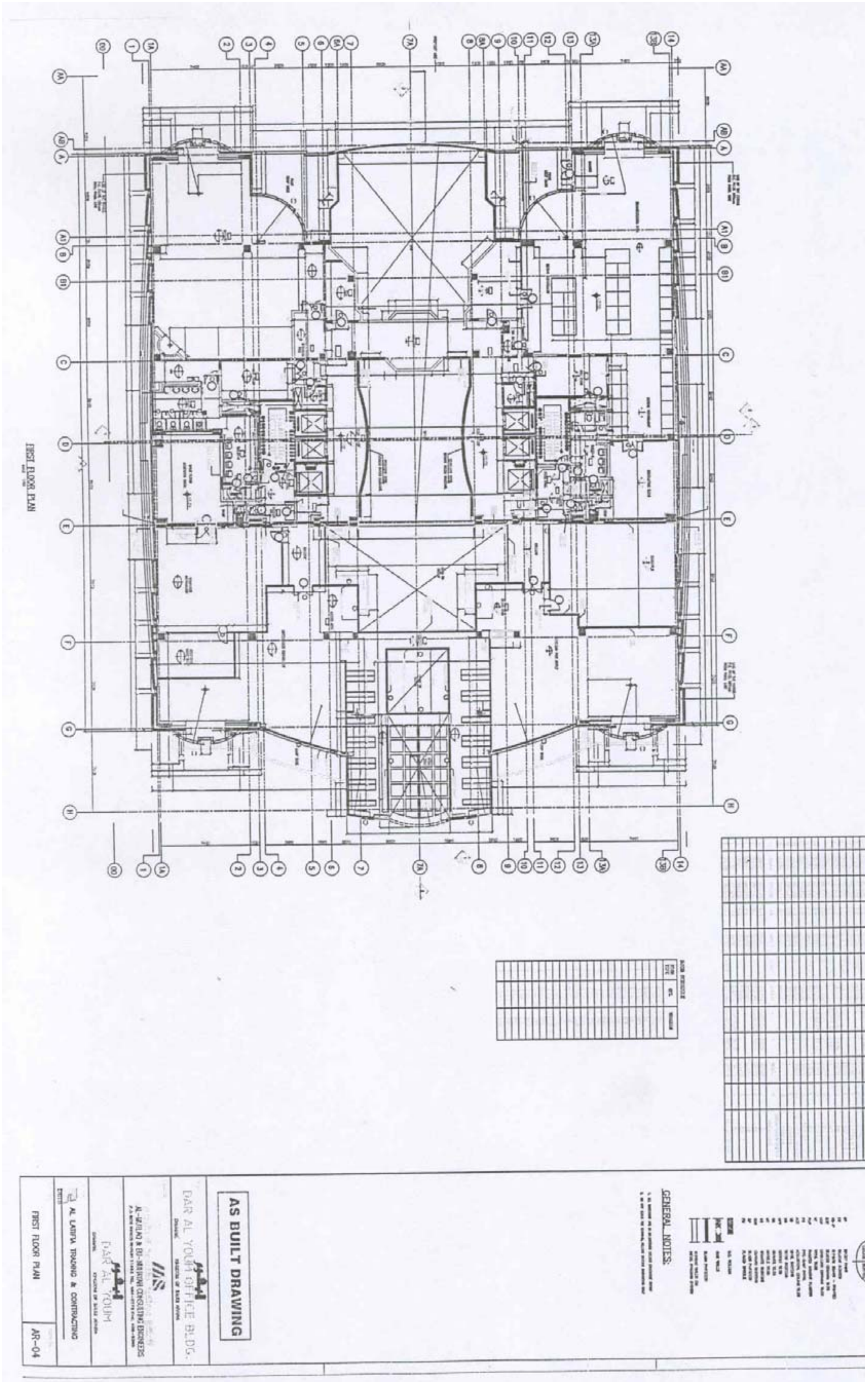


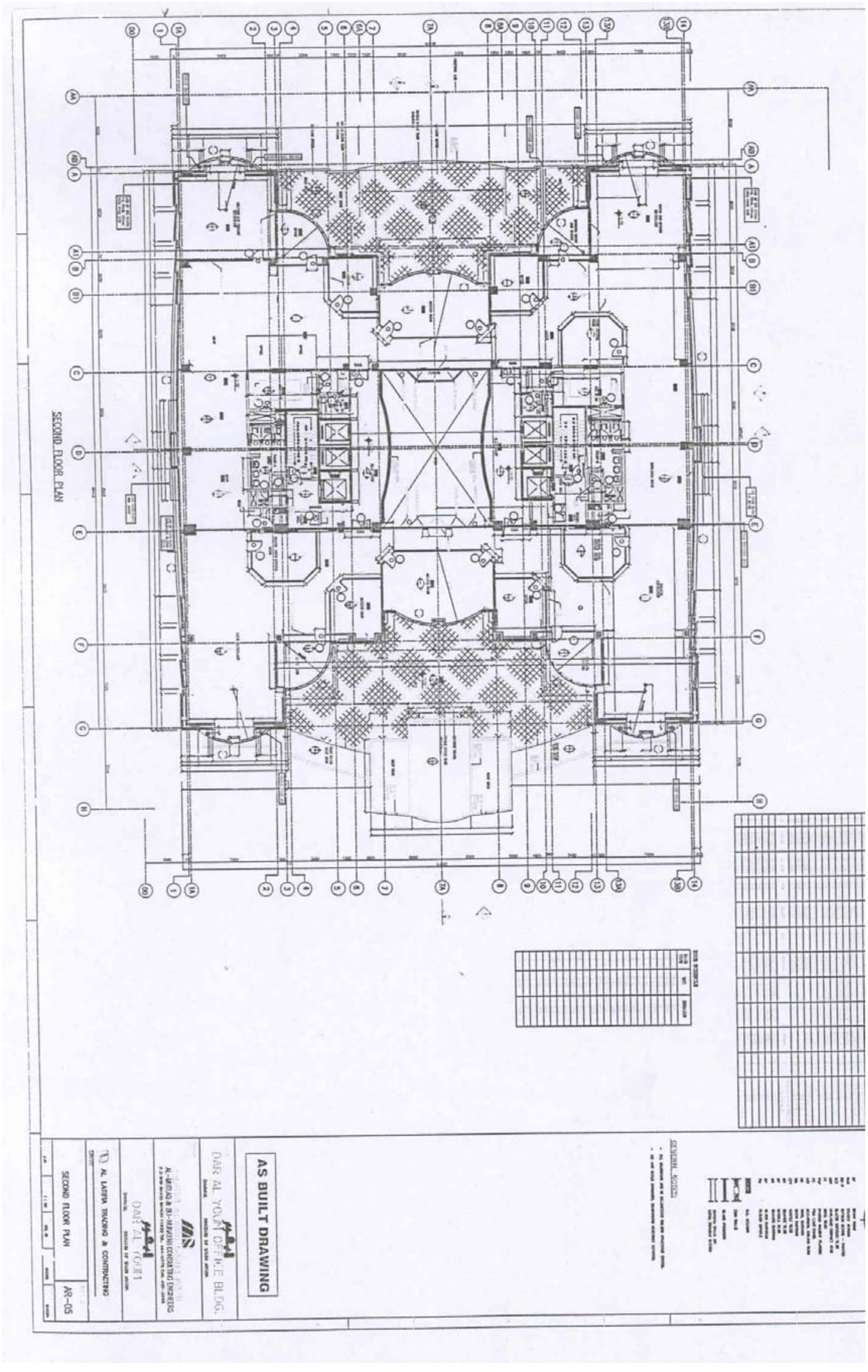
Figure A62: Winter days humidity profile for meting room

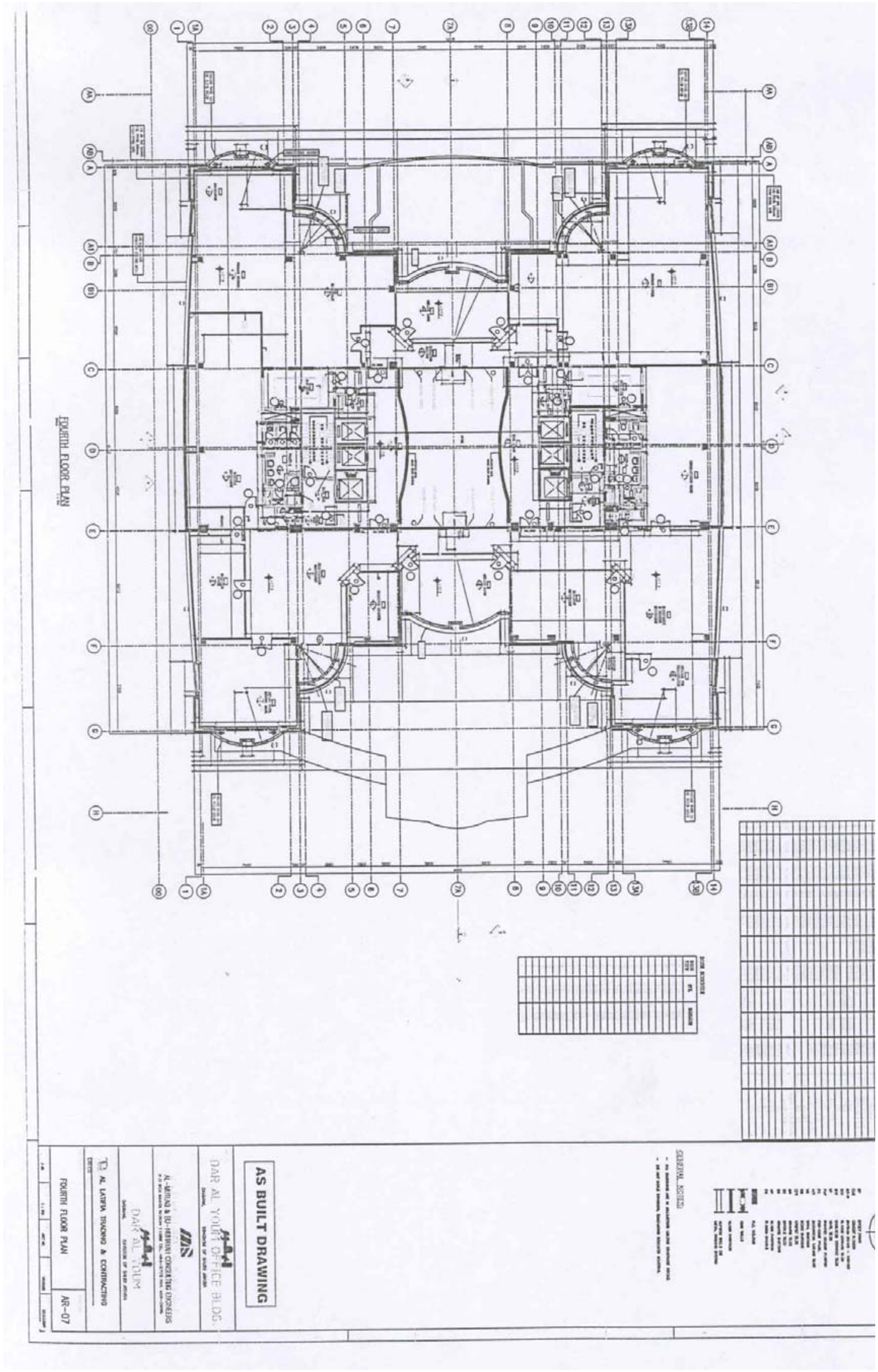
Appendix B

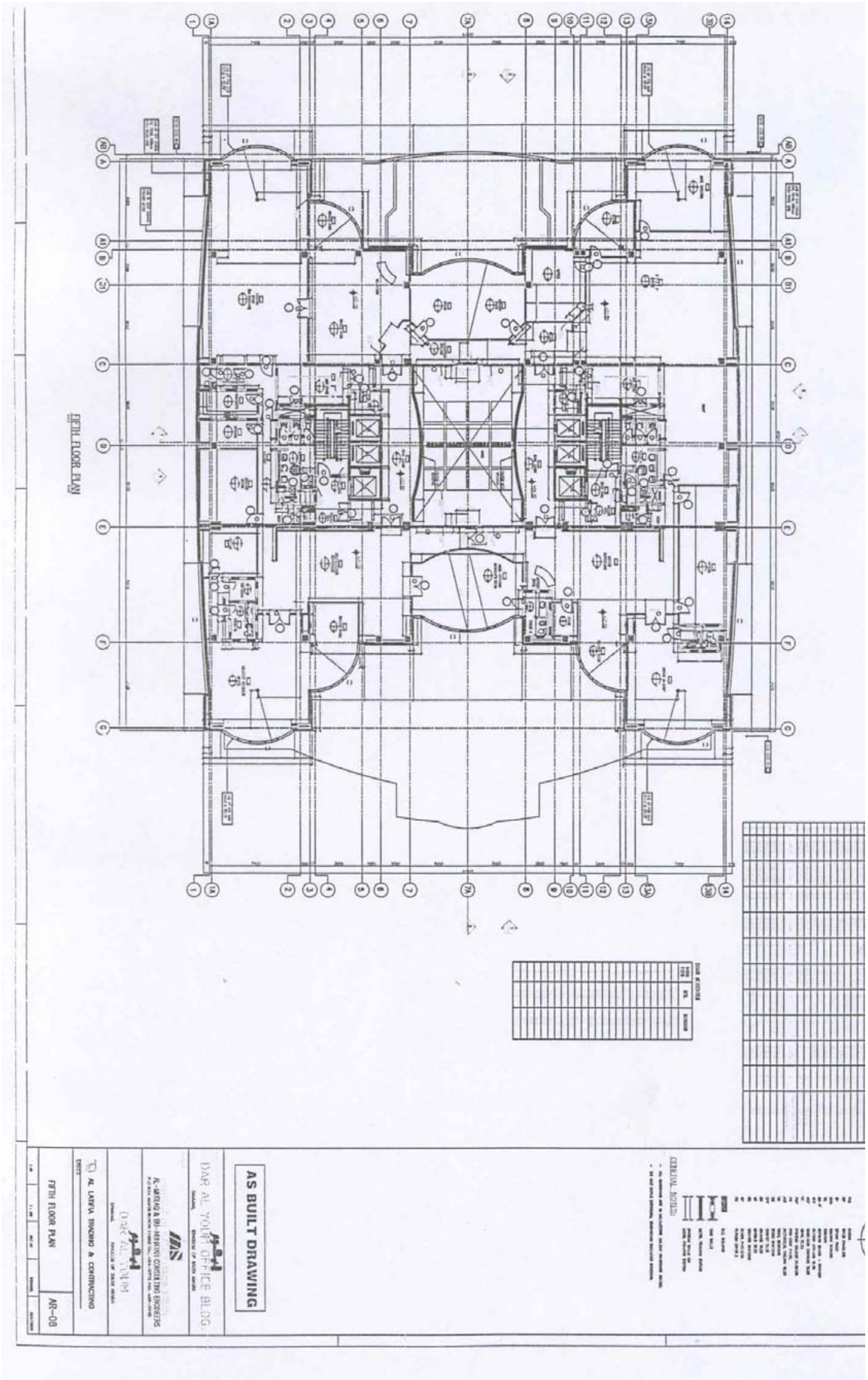
Architectural Drawings


AS BUILT DRAWING
DAR AL YOUM OFFICE BLDG.
AL LATIFA TRADING & CONTRACTING
GROUND FLOOR PLAN
AR-03


FIRST FLOOR PLAN
AS BUILT DRAWING
DAR AL YOUM OFFICE BLDG.
DAR AL YOUM
AL LATIFIA TRADING & CONTRACTING
FIRST FLOOR PLAN
AR-04
GENERAL NOTES:


SECOND FLOOR PLAN
AS BUILT DRAWING
DAR AL YOUM OFFICE BLDG.
AL LATIFA TRADING & CONTRACTING
SECOND FLOOR PLAN
AR-05


FOURTH FLOOR PLAN
AS BUILT DRAWING
DAR AL YOUM OFFICE BLDG.
FOURTH FLOOR PLAN
AR-07
GENERAL NOTES


FIFTH FLOOR PLAN
AS BUILT DRAWING
DAR AL YOUM OFFICE BLDG
AL LATIFA TRADING & CONTRACTING
AR-08
GENERAL NOTES

Appendix C

Information Request
(English & Arabic)

بسم الله الرحمن الرحيم

Ministry of Higher Education

King Fahd University of Petroleum & Minerals

COLLEGE OF ENVIRONMENTAL DESIGN

ARCHITECTURAL ENGINEERING DEPARTMENT

وزارة التعليم العالي

جامعة الملك فهد للبترول والمعادن

كلية تصاميم البيئة

قسم الهندسة المعمارية

التاريخ : / 3 / 1425هـ

الموافق : / 5 / 2004م

إلى من يهمه الأمر

السلام عليكم ورحمة الله وبركاته

يقوم قسم الهندسة المعمارية بجامعة الملك فهد للبترول والمعادن حالياً بعمل دراسة على المبنى الإداري لدار اليوم في الدمام. السيد/ عمران إقبال طالب دراسات عليا للحصول على درجة الماجستير في قسم الهندسة المعمارية، وهو الآن في مرحلة جمع المعلومات وعمل استبيان لغرض استكمال الرسالة. الغرض من هذا الاستبيان هو تقييم الراحة الحرارية وجميع المواضيع الأخرى المتعلقة بتقييم مكان العمل في المبنى.

نرجو منكم شاكرين المشاركة في توفير المعلومات المطلوبة من خلال تعبئة الاستبيان المرفق والمتعلق بموضوع الدراسة مع يقيننا بأهمية مشاركتك من أجل انجاح إستكمال هذه المرحلة من الدراسة.

شاكرين لكم سلفاً مشاركتكم الفعالة وتعاونكم بهذا الخصوص

د. / محمد سعد آل حمود

مشرف البحث

قسم الهندسة المعمارية

جامعة الملك فهد للبترول والمعادن

الظهران ٣١٢٦١ • المملكة العربية السعودية • تلفون : ٨٦٠-٣٢٧٩ (٠٣) • فاكس : ٨٦٠-٣٧٨٥ (٠٣) • تلكس : ٨٠١٠٦٠ جافهد • برقيا : الجامعة

DHAHRAN 31261, SAUDI ARABIA • Telephone: (03) 860-3279 • Fax: (03) 860-3785 • Telex: 801060 KFUPM SJ • Cable: AL-JAMAAH

بسم الله الرحمن الرحيم

Ministry of Higher Education
King Fahd University of Petroleum & Minerals
COLLEGE OF ENVIRONMENTAL DESIGN
ARCHITECTURAL ENGINEERING DEPARTMENT

وزارة التعليم العالي
جامعة الملك فهد للبترول و المعادن
كلية تصاميم البيئة
قسم الهندسة المعمارية

Date:

TO WHOM IT MAY CONCERN

Dear Sir,

The Architectural Engineering Department at the King Fahd University of Pertoleum and Minerals is presently engaged in a case study of Al-Yaum office building in Dammam.
Mr. Imran Iqbal is a Master student in the Architectural Engineering Department. He is in the data collection process and conducting a questionnaire survey for his thesis research.
The purpose of this questionnaire survey is to evaluate thermal comfort and other workplace asessment issues in this building.
We request you to kindly pariticipate in providing the needed information by filling the attached questionnaire related to the subject matter of the study. We strongly believe that your active contribution is important for the successful completion of this phase of the case study.

Thanks in advance for your positive cooperation in this regard.

Dr Mohammad S. Al-Homoud
Research Advisor
Architectural Engineering Dept.
KFUPM Dhahran

الظهران ٣١٢٦١ • المملكة العربية السعودية • تلفون : ٨٦٠-٣٢٧٩ (٠٣) • فاكس : ٨٦٠-٣٧٨٥ (٠٣) • تلكس : ٨٠١٩٥٠ جافهد • برقيا : الجامعة
DHAHRAN 31261, SAUDI ARABIA • Telephone: (03) 860-3279 • Fax: (03) 860-3785 • Telex: 801060 KFUPM SJ • Cable: AL-JAMAAH

Appendix D

Building Occupant’s Questionnaire (English & Arabic)

استبيان لتقييم الراحة الحرارية

هذا الاستبيان تم إعداده لغرض تقييم القضايا المتعلقة بالراحة الحرارية والتي تضم درجة حرارة، ورطوبة، وسرعة الهواء، وكذلك بقية المواضيع المتعلقة بتقييم مكان العمل.

بكل تأكيد سيكون من المفيد توفر الراحة في مكان عملك، تعاونك في هذا الخصوص سيكون محل تقديرنا.

معلومات عامة :

رقـم الدور الذي تعمل به:.................... نوع المكان الذي تستخدمه:............................

العمـــــــر:.................... كم عدد الساعات التي تقضيها يومياً في مكان عملك:..............

طبيعة العمل:.................... كم مضى عليك في مكان عملك هذا (أشهر):....................

موقع مكان عملك: جوار النافذة ☐ في الوسط ☐ بعيد عن النافذة ☐

أكتب إشارة (√) في المربع المناسب

رقم السؤال	العبارة	المعيار 1 طوال الوقت	2 أغلب الوقت	3 بعض الأحيان	4 نادراً	5 أبداً
1	أشعر بعدم ارتياح مع درجة حرارة الهواء في مكان عملي.					
2	أشعر بعدم ارتياح مع رطوبة الهواء في مكان عملي.					
3	لدي شعور بركود الهواء خلال ساعات العمل.					
4	أشعر بسرعة عالية في حركة الهواء في مكان عملي.					
5	أشعر بعدم كفاية التهوية لأداء عملي.					
6	لا أستطيع تعديل منظم الحرارة لتغيير درجة حرارة الهواء.					
7	انتاجيتي في العمل تتأثر عكسياً بسبب عدم الارتياح الحراري.					
8	أشعر بضغط العمل بسبب عدم الارتياح الحراري					
9	لدي شكوى متكررة حول تكييف الهواء في مكان عملي.					
10	لا أتلقى استجابة سريعة من قسم الصيانة حول التكييف.					
11	استخدم مروحة إضافية لتلطيف الهواء في مكان عملي.					

- **الحالة الحرارية عموماً في مكان عملي**

بارد جداً ☐ بارد ☐ بارد قليلاً ☐ مريح ☐ دافئ ☐ حار ☐ حار جداً ☐

- **رطوبة الهواء في مكان عملي عموماً**

رطب جداً ☐ رطب ☐ رطب قليلاً ☐ مريح ☐ جاف قليلاً ☐ جاف ☐ جاف جداً ☐

- **أشعر بعدم ارتياح حراري في مكان عملي خلال**

فصل الصيف ☐ فصل الشتاء ☐ الفصلين ☐ ليس في أي منهما ☐

من فضلك باقي الاستبيان في الوجه الآخر

استبيان لباقي مواضيع تقييم مكان العمل

رقم السؤال	العبارة	المعيار				
		1	2	3	4	5
		طوال الوقت	أغلب الوقت	بعض الأحيان	نادراً	أبداً
12	أشعر بدفء في الصيف خلال ساعات العمل بسبب أن مكان عملي معرض للخارج.					
13	لا يوجد تظليل داخلي للنوافذ لوقف الحرارة في مكان عملي (وذلك للذين مكان عملهم جوار نافذة).					
14	لا يوجد لدي نوافذ قابلة للفتح للحصول على هواء نقي.					
15	لا يوجد لدي إضاءة كافية في مكان عملي.					
16	أشعر بعدم ارتياح بصري بسبب التوهج في الإضاءة.					
17	أشعر بعدم في الخصوصية الصوتية في مكان عملي.					
18	أشعر بعدم ارتياح بسبب الضوضاء القادمة من المعدات والمصادر الأخرى.					

من فضلك أكتب أي تعليمات أو ملاحظات إضافية هنا

مع جزيل الشكر والتقدير لتعاونك في إجراء هذه الدراسة.

من فضلك أعد هذا الاستبيان لمشرفك.

Thermal Comfort Assessment Questionnaire

This questionnaire is prepared for the assessment of thermal comfort issues which include air temperature, air humidity, air velocity and other workplace assessment issues. It will be helpful for providing comfort at your workplace. Your cooperation in this regaed will be highly appreciated.

General Information

Floor # : -------------- Type of place: ------------------------------

Age : -------------- How many hours per day you spend at your workplace--------------

Nature of work: -------------- How long have you been in this work place (months)------------------

Location of workplace ☐Close to window ☐at center ☐away from window

Please mark (✓) at appropriate box

Q#	Statements	Scale				
		1	2	3	4	5
		All the time	Most of the time	Some time	Seldom	Never
1	I feel uncomfortable with air temperature at my workplace					
2	I feel uncomfortable with air humidity at my workplace					
3	I have stuffy feeling during working hours					
4	I feel swift air movement at my work place					
5	I cannot adjust thermostat for changing air temperature					
6	I feel inadequate ventilation for performing my work					
7	My working productivity is adversly affected due to thermal discomfort					
8	I feel job stress due to thermal discomfort					
9	I have frequent complaints about air-conditioning at my workplace					
10	I don't get quick response from maintenance department					
11	I use pedestal fan for more cooling at my work place					

The overall thermal condition at my work place is

Too cold	Cold	Slightly cold	Comfortable	Slightly warm	Hot	Too hot

The overall air humidity at my work place is

Too humid	Humid	Slightly humid	Comfortable	Slightly dry	Dry	Too dry

I feel thermally uncomfortable at my workplace during

☐Summer ☐Winter ☐Both ☐Niether

Please turn over the page

Other Workplace Assessment Questionnaire

Q#	Statements	Scale				
		1	2	3	4	5
		Strongly agree	Agree	Neutral	Disagree	Strongly disagree
12	I feel warm in summer during office hours because my work place is exposed to outside					
13	I don't have interior shading for window to stop heat at my workplace(for those having workplace near window)					
14	I don't have operable windows for getting fresh air					
15	I have inadequate lighting at my workplace					
16	I feel visual discomfort due to glare from the lights					
17	I feel lack of voice privacy at my work place					
18	I feel discomfort from noise coming from equipments and other sources					

Please add any additional comments below

Thank you. I appreciate your cooperation in carrying out this study.
Please return back these questionnairs to your supervisor.

Appendix E

Details of AHU's & Chillers
Schedules of Condenser & Pumps

Table E1: Air handing unit schedule for Al-youm office building

AHUs SCHEDULE

TITLE	QTY	AIR/LS	COOLING CAPACITY Kw	WATER SUPPLY L/S	ENT-AIR TEMP Db/Wb	LEAVING AIR TEMP Db/Wb	ENT C.W. °C	LVNG C.W. °C	STATIC Pr. EXT. Pa	HEATER Kw	STEAM HUMIDIFIER Kg/Hr	AREA SERVED	REMARKS
AHU 1,3, 4,5,6	5	3500	58	2.4	26/18	13.1/12.7	7	13	750	10	7.5	PRESS HALL WEST SIDE	ROOM TEMP.: 25°C ±1; RH-50%±5 CARRIER, MODEL 39FX-360 OR APPROVED EQUAL. PREFILTER, BAGFILTER. V.F.D MOTOR. 15% F.A.
AHU 2	1	1600	42	1.8	27/19	11.2/10.5	7	13	500	10	-	LVL-1, W/SHOP + P.CUBICLES	ROOM TEMP.: 25°C ±1 CARRIER, MODEL 39FX-330 OR APPROVED EQUAL. PREFILTER, BAGFILTER. 15% F.A.
AHU 7	1	2380	55	2.2	27/19	12.3/11.5	7	13	500	10	-	C.T.P + CONTROL ROOM	ROOM TEMP.: 25°C ±1 CARRIER, MODEL 39FX-350 OR APPROVED EQUAL. PREFILTER, BAGFILTER. 15% F.A.
AHU 8	1	1720	45	2	27/19	11.3/10.9	7	13	500	10	-	LVL-0, ELECT. + INK DAMPENING	ROOM TEMP.: 25°C ±1 CARRIER, MODEL 39FX-340 OR APPROVED EQUAL. PREFILTER, BAGFILTER. 15% F.A.
AHU 9	1	1450	27	1.2	26/18	12.5/11.9	7	13	500	10	7.5	LVL-0 STORE	ROOM TEMP.: 22°C ±1; RH-55%±5 CARRIER, MODEL 39FX-330 OR APPROVED EQUAL. PREFILTER, BAGFILTER. 15% F.A.
AHU 10	1	7700	203	8.2	27/19	11.5/11.0	7	13	750	10	7.5	COMMERCIAL PRESS	ROOM TEMP.: 25°C ±1; RH-50%±5 CARRIER, MODEL 39FX-660 OR APPROVED EQUAL. PREFILTER, BAGFILTER. 15% F.A.
AHU 11	1	6200	181	7.3	27.8/19.8	11.5/10.5	7	13	750	10	7.5	GOSS	ROOM TEMP.: 25°C ±1; RH-50%±5 CARRIER, MODEL 39FX-560 OR APPROVED EQUAL. PREFILTER, BAGFILTER. 15% F.A.
AHU 12	1	6200	181	7.3	27.8/19.8	11.5/10.5	7	13	750	10	7.5	GOSS	ROOM TEMP.: 25°C ±1; RH-50%±5 CARRIER, MODEL 39FX-560 OR APPROVED EQUAL. PREFILTER, BAGFILTER. 15% F.A.
AHU 13	1	1600	27	1.2	26.1/18.3	14.0/13.3	7	13	500	5	-	LVL-0 OFFICES	ROOM TEMP.: 25°C ±1 CARRIER, MODEL 40RMS 010 OR APPROVED EQUAL. PREFILTER, BAGFILTER. 15% F.A.
AHU 14	1	1600	27	1.2	26.1/18.3	14.0/13.3	7	13	500	5	-	LVL-1 OFFICES	ROOM TEMP.: 25°C ±1 CARRIER, MODEL 40RMS 010 OR APPROVED EQUAL. PREFILTER, BAGFILTER. 15% F.A.
AHU 15	1	2250	40	1.72	26.8/18	13.5/12.7	7	13	500	5	-	LVL-1 CAFETERIA	ROOM TEMP.: 25°C ±1 CARRIER, MODEL 40RMS 016 OR APPROVED EQUAL. PREFILTER, BAGFILTER. 15% F.A.
AHU 16	1	2250	44	1.89	26.8/18	13.5/12.7	7	13	500	5	-	LVL-2 OFFICES	ROOM TEMP.: 25°C ±1 CARRIER, MODEL 40RMS 016 OR APPROVED EQUAL. PREFILTER, BAGFILTER.
AHU 17,18,19 20,21	5	1380	31	1.34	26.8/18	11.5/10.6	7	13	500	-	7.5	ROOF-AREA	ROOM TEMP.: 25°C ±1; RH-50%±5 CARRIER, MODEL 39FX-330 OR APPROVED EQUAL. PREFILTER, BAGFILTER.
M/AHU 1-10	10	1000	19	0.78	26.8/18	13.0/12.5	7	13	250	-	-	EAST SIDE HALL	ROOM TEMP.: 25°C ±1; RH-50%±5 CARRIER, MODEL 40RMS 008 OR APPROVED EQUAL. PREFILTER, V.F.D MOTOR.
M/AHU 11-20	10	1000	19	0.78	26.8/18	13.0/12.5	7	13	250	-	-	WEST SIDE HALL	ROOM TEMP.: 25°C ±1; RH-50%±5 CARRIER, MODEL 40RMS 008 OR APPROVED EQUAL. PREFILTER, V.F.D MOTOR.
FCU 1-13	13	650	17.5	0.75	29.3/22	16.0/14.3	7	13	-	-	3	REEL ROOM	ROOM TEMP.: 25°C ±1; RH-50%±5 CARRIER, MODEL 42D OR APPROVED EQUAL.

Table E2: Pump schedule for al-youm office building

PUMP SCHEDULE

SNo.	TITLE	QTY	FLOW L/S	HEAD m	POWER 220/3/60	PUMP TYPE	PANEL DETAIL
1	POTABLE WATER PUMP	3	6.5	75	6KW	VERTICAL INLINE	2 DUTY/1 STANDBY DRY RUN PROTECTED
2	CHILLED WATER PUMP	4	32	10	5KW	CONSTANT SPEED	PRIMARY PUMP
3	CHILLED WATER PUMP	4	40	30	23KW	VARIABLE SPEED	SECONDARY PUMP VARIABLE SPEED WITH VARIABLE FREQUENCY DRIVE
4	IRRIGATION PUMP	2	3	25	2KW	CENTRIFUGAL	CONTROL PANEL WITH TIME SCHEDULE
5	FIRE PUMP	1	5670 L/MIN	90	105	ELECTRIC MOTOR DRIVE	CONTROL PANEL
6	FIRE PUMP	1	5670 L/MIN	90	105	DIESEL ENGINE DRIVE	CONTROL PANEL COMPLETE WITH ALL ACCESSORIES
7	JOCKEY PUMP	1	9	90	2	ELECTRIC MOTOR DRIVE	CONTROL PANEL COMPLETE WITH ALL ACCESSORIES
8	CHILLED WATER PUMP	2	6	60	4	ELECTRIC MOTOR DRIVE	FOR PRESS COOLING SYSTEM (22° – 26°C)
9	CHILLED WATER PUMP	2	9	60	4	ELECTRIC MOTOR DRIVE	FOR PRESS COOLING SYSTEM (12° – 14°C)

Table E3: Timings of Air handing units for Al-youm office building

TIMING SCHEDULE (AHU)

FLOOR LEVEL	CONTROL BY CHILLERS #1 & #2 (left wing)		CONTROL BY CHILLERS #3 & #4 (right wing)	
	ZONE 1	ZONE 2	ZONE 3	ZONE 4
GROUND	(CONTINUE) AHU # 1 (10HP) TEMP. SET – 23C DEVELOPING sect. MONTAGE section TELEPHONE sect. SATTELITE room	11:00 AM – 2:30 PM AHU # 2 (10HP) TEMP SET – 16C AUDITORIUM FAN COIL UNIT (2) NOS. 3 & 4 (2EA) TEMP SET – HIGH MEETING ROOM	6:00AM – 8:00 PM AHU # 4 (10HP) TEMP SET – 22C ADVERTISING Sect. FAN COIL UNIT (2) NOS. [illegible] &19 8:00 AM – 3:00 PM TEMP SET – HIGH ADVERTISING sect.	6:00AM 12:00 M/N AHU # 3 (10HP) TEMP SET – 24C CANTEEN 8:00 AM.- 7:00 PM AHU # 25 (1.5HP) TEMP SET – 20C TRAINING ROOM
FIRST	(CONTINUE) AHU # 6 (10HP) TEMP SET – 23C COMPUTER DEPT. AND INTERNET	10:30 AM – 1:00 PM 3:00 PM – 9:30 PM 4:00AM – 5:30AM AHU # 5 (7.5HP) TEMP SET – 20C MOSQUE	6:00AM – 8:00 PM AHU # 8 (10HP) TEMP SET – 23C DESIGN SECTION PUBLICATION sect	6:00AM – 2:30 AM AHU # 7 (7.5HP) TEMP SET – 23C EDITING DEPT.
SECOND	7:00 AM – 11:00 PM. AHU # 9 (10HP) TEMP SET – 23C POLITICAL section	7:30 AM – 10:00 PM AHU # 10 (10HP) TEMP SET – 23C ASSISTANT editor	7:30AM – 2:00 AM AHU # 12 (10HP) TEMP SET – 23C LOCAL NEWS sect.	7:00 AM –1:00 PM AHU # 11 (10HP) TEMP SET – 23C SPORTS SECTION
THIRD	CLOSED AHU # 14 (10hp)	CLOSED AHU # 13 (10hp)	CLOSED AHU # 16 (10hp)	CLOSED AHU # 15 (10hp)
FOURTH	6:00AM – 8:00 PM AHU # 18 (10HP) TEMP SET – 22C Asst managing Dir. FAN COIL UNIT (1) Small meeting room	6:00AM – 3 :30 PM AHU # 17 (10HP) TEMP SET – 20C ACCOUNTING FAN COIL UNIT (1) Small meeting room	6:00AM – 3:30 PM AHU # 20 (10HP) TEMP SET – 23C ADMINISTRATION FAN COIL UNIT (1) Small meeting room	6:00 AM – 5:00 PM AHU # 19 (10HP) TEMP SET – 23C Manager maintenance Manager press
FIFTH	6:00AM – 10:00 PM AHU # 22 (10HP) TEMP SET – 22C Managing Director	9:30AM – 1:00 PM AHU # 21 (10HP) TEMP SET – 18C Big meeting room FAN COIL UNIT (1) small meeting room	6:00AM – 10:00 PM AHU # 24 (10HP) TEMP SET – 23C CHIEF EDITOR	1:00 PM – 4:00 PM AHU # 23 (10HP) TEMP SET – 23C OFFICE w/ furniture FAN COIL UNIT (1) Small meeting room

Appendix F

Utility Bills Data

Table F1: Timings of Air handing units for Al-youm office building

كهرباء المبنى الادارة العامة

متوسط سعر الكيلوواط	متوسط اليوم ريـــال	متوسط اليوم كيلو واط	القيمة ريـــال	كمية الاستهلاك كيلو واط	المدة يوم	الفترة الى	الفترة من	رقم العداد
0.1903	1,518.40	7,981	58,309.35	306,000	38	16-ابريل-00	10-مارس-00	
0.3667	5,419.96	14,780	143,021.90	390,000	26	13-مايو-00	16-ابريل-00	زيادة سعر
0.3660	5,141.37	14,048	149,099.85	407,400	29	11-يونيو-00	13-مايو-00	اجمالي
0.3671	5,338.20	14,540	160,146.00	436,200	30	11-يوليو-00	11-يونيو-00	الثلاث
0.3681	6,000.33	16,300	180,010.00	489,000	30	10-اغسطس-00	11-يوليو-00	عدادات
0.3669	5,537.27	15,091	182,730.00	498,000	33	12-سبتمبر-00	10-اغسطس-00	لعام
0.3645	4,638.20	12,724	134,507.85	369,000	29	11-اكتوبر-00	12-سبتمبر-00	2000م
0.3651	4,690.36	12,845	103,188.00	282,600	22	02-نوفمبر-00	11-اكتوبر-00	
0.2517	3,386.87	13,457	23,708.10	94,200	7	05-نوفمبر-00	02-نوفمبر-00	تخفيض سعر
0.2484	2,627.28	10,575	84,072.90	338,400	32	06-ديسمبر-00	05-نوفمبر-00	
0.2470	2,313.55	9,368	71,720.10	290,400	31	06-يناير-01	06-ديسمبر-00	
0.2468	2,441.11	9,893	68,351.10	277,000	28	02-فبراير-01	06-يناير-01	اجمالي
0.2474	2,392.42	9,669	62,202.90	251,400	26	28-فبراير-01	02-فبراير-01	الثلاث
0.2490	2,770.82	11,127	91,437.00	367,200	33	01-ابريل-01	28-فبراير-01	عدادات
0.2506	3,242.40	12,940	97,272.00	388,200	30	01-مايو-01	01-ابريل-01	
0.2572	3,703.26	14,400	118,504.30	460,800	32	01-يونيو-01	01-مايو-01	دمج العدادات
0.2571	3,734.60	14,524	108,303.30	421,200	29	30-يونيو-01	01-يونيو-01	
0.2574	4,058.39	15,766	117,693.30	457,200	29	28-يوليو-01	30-يونيو-01	لعام
0.2576	4,296.13	16,680	128,884.00	500,400	30	27-اغسطس-01	28-يوليو-01	2001م
0.2573	3,838.53	14,920	115,156.00	447,600	30	25-سبتمبر-01	27-اغسطس-01	
0.2569	3,401.73	13,240	102,052.00	397,200	30	25-اكتوبر-01	25-سبتمبر-01	
0.2566	3,042.52	11,859	103,445.70	403,200	34	27-نوفمبر-01	25-اكتوبر-01	
0.2564	2,864.76	11,175	91,672.30	357,600	32	29-ديسمبر-01	27-نوفمبر-01	
0.2562	2,826.87	11,035	65,018.00	253,800	23	21-يناير-02	29-ديسمبر-01	2002م
0.2559	2,552.18	9,972	74,013.30	289,200	29	19-فبراير-02	21-يناير-02	
0.2564	2,889.13	11,269	92,452.30	360,600	32	22-مارس-02	19-فبراير-02	اجمالي
0.2566	3,063.22	11,938	88,833.30	346,200	29	20-ابريل-02	22-مارس-02	الثلاث
0.2567	3,416.83	13,310	99,088.00	386,000	29	19-مايو-02	20-ابريل-02	عدادات
0.2572	3,729.33	14,500	111,880.00	435,000	30	18-يونيو-02	19-مايو-02	لعام
0.2573	3,943.49	15,329	122,248.30	475,200	31	19-يوليو-02	18-يونيو-02	2002م
0.2572	3,830.49	14,893	107,253.70	417,000	28	16-اغسطس-02	19-يوليو-02	
0.2570	3,605.10	14,028	104,548.00	406,800	29	14-سبتمبر-02	16-اغسطس-02	
0.2568	3,297.73	12,840	98,932.00	385,200	30	14-اكتوبر-02	14-سبتمبر-02	
0.2565	3,083.48	12,021	86,337.30	336,600	28	11-نوفمبر-02	14-اكتوبر-02	
0.2553	2,223.26	8,708	82,260.70	322,200	37	18-ديسمبر-02	11-نوفمبر-02	
0.2553	2,297.83	9,000	52,850.00	207,000	23	10-يناير-03	18-ديسمبر-02	2003م
0.2549	2,017.47	7,915	52,454.30	205,800	26	05-فبراير-03	10-يناير-03	
0.2549	2,052.73	8,052	63,634.70	249,600	31	08-مارس-03	05-فبراير-03	اجمالي
0.2554	2,243.96	8,787	69,562.70	272,400	31	08-ابريل-03	08-مارس-03	الثلاث
0.2557	2,502.72	9,788	80,087.00	313,200	32	10-مايو-03	08-ابريل-03	عدادات
0.2563	2,826.53	11,028	81,969.30	319,800	29	08-يونيو-03	10-مايو-03	لعام
0.2567	3,239.31	12,621	93,940.00	366,000	29	07-يوليو-03	08-يونيو-03	2003م
0.2566	3,046.15	11,873	100,523.00	391,800	33	09-اغسطس-03	07-يوليو-03	
0.2567	3,255.45	12,683	94,408.00	367,800	29	07-سبتمبر-03	09-اغسطس-03	
0.2562	2,772.35	10,819	85,942.70	335,400	31	08-اكتوبر-03	07-سبتمبر-03	
0.2558	2,582.05	10,093	72,297.30	282,600	28	05-نوفمبر-03	08-اكتوبر-03	
0.2551	2,110.15	8,273	69,635.00	273,000	33	08-ديسمبر-03	05-نوفمبر-03	
0.2548	2,075.81	8,145	68,501.70	268,800	33	10-يناير-04	08-ديسمبر-03	2004م
0.2550	2,062.95	8,091	72,203.30	283,200	35	14-فبراير-04	10-يناير-04	
0.2550	2,141.83	8,400	49,262.00	193,200	23	08-مارس-04	14-فبراير-04	اجمالي
0.2554	2,285.06	8,945	75,407.00	295,200	33	10-ابريل-04	08-مارس-04	الثلاث
0.2557	2,487.33	9,729	69,645.30	272,400	28	08-مايو-04	10-ابريل-04	عدادات
0.2564	2,898.15	11,303	89,842.70	350,400	31	08-يونيو-04	08-مايو-04	لعام
0.2567	3,238.98	12,619	100,408.30	391,200	31	09-يوليو-04	08-يونيو-04	2004م
0.2569	3,334.13	12,980	100,024.00	389,400	30	08-اغسطس-04	09-يوليو-04	
0.2568	3,358.76	13,080	100,762.70	392,400	30	07-سبتمبر-04	08-اغسطس-04	
0.2563	2,835.51	11,063	90,736.30	354,000	32	09-اكتوبر-04	07-سبتمبر-04	
0.2560	2,726.90	10,650	76,353.30	298,200	28	06-نوفمبر-04	09-اكتوبر-04	

Appendix G

Details of input data for the base case and various Energy conservation measures

Table G1: Input data for Base Case and ECMs

Component	Base case	Energy Conservation Measures ECMs
Insulated Wall	75mm Polyutherene Insulation	50mm Polyutherene Insulation
Insulated Roof	75mm Polyutherene Insulation	50mm Polyutherene Insulation
Double Glazed Window (6/12/6mm)	U=3.5 W/m^2K	U=1.8 W/m^2K
	SC=0.3	SC=0.14
	SHGC=0.26	SHGC=0.12
	Trasmittance=0.7	Trasmittance=0.7
	Colour=blue	Colour =silver
Energy Efficient lamps	40 watts Fluorescent Type	34 watts Fluorescent Type
Set Point Temperature	24^{o}C (summer) and 22^{o}C (winter)	26^{o}C (summer) and 20^{o}C (winter)
Night Time Setback	Not Used	28^{o}C (summer) and 16^{o}C (winter)
Schedule of Lighting & Equipment	Used all the time	Turn off during low occupancy and night hours
HVAC system	Constant volume system	Variable air volume system
	Reciprocating chillers	More efficient air cooled reciprocating chillers